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SUMMARY OF ARIZONA DEPARTMENT OF TRANSPORTATION EXPERIENCE WITH ASPHALT RUBBER

State of the Art

Final Report

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ADOT has been performing research and using asphalt-rubber since 1967. This report contains a summary of the research sponsored by ADOT on the development of the product. The status of the research - experimental projects, field tests, of asphalt-rubber is reviewed and evaluated. The performance of the asphalt-rubber sections identified in the pavement management data base were analyzed and compared to conventional treatments. The performance and economic analysis show stress absorbing membranes need to last twice as long as surface treatments to be cost effective while a stress absorbing membrane interlayer is comparable to a four inch overlay.

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PREFACE

This report was sponsored by the Arizona Transportation Research Center through the man-year faculty agreement with the Center for Advanced Research in Transportation. The objective of the study was to summarize the state-of-the-knowledge of asphalt-rubber use by the Arizona Department of Transportation.

The content of this report reflects the views of the author who is responsible for the facts and interpretation of the data presented. The contents do not necessarily reflect the official views of the Arizona Department of Transportation or the Arizona Transportation Research Center. This report does not constitute a standard, specification, or regulation.

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EXECUTIVE SUMMARY

OVERVIEW

This report presents a review of the status of the research and performance of asphalt-rubber in Arizona. Asphalt-rubber was developed primarily by Charles McDonald as a material for the repair of distressed areas of pavements. The use of asphalt-rubber has been extended to stress absorbing membranes, SAM, and stress absorbing membrane interlayers, SAMI.

In 1967 ADOT constructed their first SAM section. Subsequently, the department has sponsored both laboratory research and field experiments. In the mid 1970's SAMs and SAMIs were constructed on a routine basis. The pavement management data base contains 37 SAM and 58 SAMI sections.

The laboratory program sponsored by ADOT examined the viscosity and ductility of asphalt-rubber in detail. At the time the ADOT research was performed the asphalt-rubber was more variable material than neat asphalt cement. There was disagreement between the researchers as to the adequacy of standard test procedures for use in quality control of asphalt-rubber. While the variability of asphalt-rubber samples prepared in the laboratory causes concern to researchers, the variability of asphalt-rubber produced in the field was even greater than laboratory variability. There was concern that materials developed, tested, and approved in the laboratory could not be reproduced in the field. Unfortunately, the one experiment performed to test this hypothesis verified the lack of continuity between the field and laboratory. Nevertheless, the laboratory experiments have

demonstrated that adding rubber to asphalt has several beneficial effects:

1) Reduction of temperature sensitivity.

2) Improved ductility, particularly at low temperatures.

3) Ability to resist horizontal and vertical shear stresses for the control of reflection cracking.

4) Adds an elastic component to the asphalt cement.

5) Attenuates strain and relieves stress.

The ADOT research was conducted prior to 1982. The asphalt-rubber industry continued research with the material. In 1981 to 1982 a blender was developed to premix the asphalt-rubber. Data provided by International Surfacings Inc. supports the industry claim that the product is now more uniform and there is a correlation between laboratory and field mixes.

The performance of asphalt-rubber is being evaluated on several research-experimental projects, REP. These are projects that were designed and constructed to evaluate specific performance features. There are currently 19 sections in the research-experimental data files. Six of these sections have some forms of serious distress. The remaining sections are in good condition. One of these projects, Beeline Highway, was evaluated during this project, using a detailed condition survey procedure.

The best current source of data on the performance of asphalt-rubber in Arizona is in the pavement management system data base. The majority of the data required for the evaluation of pavement performance are in the PMS data base. The information on construction history is adequate for research purposes, provided the data on layer thicknesses are verified whenever cores are taken from the pavements. Unfortunately, the traffic history data lacks reliability. The PMS data base contains records on cracking, roughness, and Mu Meter (skid) histories. These data are collected for network pavement management purposes. The data quality needs of research and network pavement management are vastly different.

Regardless of the limitations of the data, the analysis of the pavement management data base demonstrated the performance of the SAM and SAMI sections with respect to distress is very good. Relatively few sections have developed significant cracking since the SAMs and SAMIs were constructed. The roughness data is more variable as shown by the graphs in Appendix B. The data were analyzed to determine if performance models could be developed. Several of the sections demonstrated a good correlation between annual change in roughness and time since the SAM or SAMI was placed. In general, the annual change in roughness is in the range of 7.0 to 14.3 inches per mile.

The pavement management data base was also used to analyze the performance of seal coats and overlays. In general, the performance of the conventional treatments compares favorably with the performance of the asphalt-rubber sections. The PMS data base does not contain information on the condition of the pavements prior to placing any of the treatments. The former ADOT research engineer, Mr. Gene Morris, contends asphalt-rubber treatments were only used on pavements in a highly distressed condition where engineering judgement indicated a surface treatment or thin overlay would not perform adequately. Under this hypothesius, direct comparison of the asphalt-rubber and conventional treatments in the PMS data base is biased in favor of the conventional treatments.

Finally, the cost-effectiveness of asphalt-rubber was analyzed. Due to the higher initial construction costs, asphalt-rubber sections need to perform twice as long as conventional treatments to be cost effective.

RECOMMENDATIONS

Based on the information collected and analysis performed during this research, asphalt-rubber has served Arizona well, and there is no indication that the situation will change in the future. The state of the knowledge should be improved in several areas.

Laboratory Experiments

The issue of the variability of asphalt-rubber properties should be further researched. The disagreement between researchers during ADOT sponsored research on the reliability of viscosity measurements needs to be resolved. Control of materials is of particular concern; especially with respect to the inability of laboratories and manufacturers to produce materials, with a common set of specifications, that have the same properties. The contention of the industry that modern blending techniques produce a higher quality material with low variability should be verified with independent research.

A new area of concern is the ability to recycle asphalt-rubber. There has not been any research to determine if asphalt-rubber can be cold recycled or on what will happen if asphalt-rubber is recycled through a central plant.

Field Experiments

ADOT can potentially obtain valuable information from the research-experimental projects sections. However, the data collection procedures currently used are inadequate. First, the project files should be upgraded to include all construction and traffic data. The performance data also should be upgraded. A standard pavement condition survey procedures, which contains all the major forms of distress should be adopted. Observers should be trained and objective measures of distress should be recorded for the entire length of each research section. The roughness data should be collected using a procedure which will provide an accurate measurement of the mean roughness of each section each year. If the Mays meter is used for the roughness measurements, then the quality of the calibration procedure should be reexamined. The number of calibration sections should be increased. In addition, multiple roughness measurements should be obtained over a short time span (but not one day) on each section so an accurate mean roughness can be established.

Highway Section Performance

Currently the pavement management data base contains the best source of information on the performance of asphalt-rubber. However, these data were not intended for research and they cannot be expected to totally fulfill the needs of research. If the performance of pavements, whether they are asphalt-rubber or conventional construction, is going to be modeled, the quality of the data must be upgraded. The research quality data are not required for the entire network; a representative sample of the network can be selected to provide the required data. Statistical methods should be used to select the sample. Once the sample is established, then the data collection procedures developed for the research-experimental projects should be applied to get quality performance data.

CONCLUSIONS

The central question concerning asphalt-rubber is whether or not the material is cost effective when compared to conventional treatments. Three types of analyses were performed during this project to determine if asphalt-rubber section performance is superior to conventional treatments. The Beeline Highway experimental project was examined using a detailed pavement condition evaluation procedure described in Appendix A. The second approach was to examine the pavement management system data base for adjacent road sections where the only difference in the construction history was the use of asphalt-rubber on one part of the road, and a conventional treatment on the adjacent section of the road. Three sections were found which satisfied this criteria; each was evaluated using the procedure in Appendix A. The third analysis was an evaluation of the performance data in the pavement management system data base for SAM, SAMI, seal coat, and overlay treatments. Pavement sections were evaluated with respect to cracking, roughness, and average maintenance costs. In each of the analyses, the performance of the conventional and asphalt-rubber treatments were very similar.

The SAM treatments need to last twice as long as a seal coat in order to be cost effective. SAMI treatments with a two inch cover need to last twice as long as a two inch overlay in order to be cost effective. However, in the analysis performed herein, the SAMI with a two inch cover was more economical than a four inch overlay for a short (two mile) project whereas the life cycle cost of these two treatments were about equal for a longer (10 mile) project.

CHAPTER I. INTRODUCTION

Asphalt was originally a waste material which could be economically sprayed on gravel and earth roads to control dust. Over the years, through specifications and controls, the properties of asphalt were regulated to obtain a uniform material with consistent properties. However, even under ideal conditions, asphalt cement has limitations as a binder for pavement surfaces. The need for long lasting pavements, both new and resurfaced, is critical in the face of the high cost of closing facilities for maintenance and repair. According to the May 1986 issue of Roads and Bridges (Ref. 1), there is a new wave of asphalt modifiers entering the market to improve asphalt performance.

One class of the new wave materials is elastomers produced from natural, synthetic, or reclaimed rubber. Reclaimed rubber replaces 20 to 30% of the asphalt in the binder. The Federal Highway Administration recommends the evaluation of modified asphalt with respect to four areas (Ref. 1):

1. the effect of the product on plant operation
2. the effect on field operations
3. long term performance
4. cost-effectiveness.

HISTORICAL ASPECTS OF ASPHALT-RUBBER USE

Contrary to the terminology used in the Roads and Bridges article, asphalt modified with reclaimed rubber is not a "new wave" material. Experiments on the blending of asphalt and rubber began in the late 1920's, however modern technology in the use of asphalt-rubber started in the early 1960's by Charles H. McDonald (Ref. 2 and 3). In 1967 the

Arizona Highway Department authorized construction of the first seal coat using reclaimed rubber in combination with asphalt for use as a binder on chip seal coats (Ref. 4). Through experimentation and perseverance the issues of plant and field operations have been largely resolved. In 1968, Sahuaro Petroleum and Asphalt Company of Phoenix began the development of equipment and procedures for production and application of asphalt-rubber (Ref. 4). In 1975 the Arizona Refining Company of Phoenix entered the asphalt-rubber market (Ref. 3). In a 1984 nationwide survey of asphalt-rubber use, 90 percent of all sections identified in the U.S. were constructed by either Sahuaro Petroleum or Arizona Refining Company. The other 10 percent of asphalt-rubber applications were experimental projects placed by state agencies or local contractors (Ref. 5). The limited number of suppliers of asphalt-rubber has ensured a certain amount of uniformity in the material. The impact of the material on plant operations has been limited due to the limited number of suppliers.

To a large extent the impact of the material on field operations has been minimized by the same mechanism. Construction of asphalt-rubber seal coats, or membranes, uses conventional construction procedures and equipment with the exception of a specially designed asphalt distributor truck. As with all pavement types, poor construction procedures, or failure to adhere to specifications will result in poor pavement performance. According to Ford and Lansdon (Ref. 4),

> "The major problem that we have had to overcome for the successful placement of asphalt-rubber has been human, and specification enforcement. I am sure you have noticed, there are no exotic formulas or methods, simply strict adherence to the specifications."

A similar conclusion was arrived at by Shuler, Pavlovich, and Epps (Ref. 5).

> "The negative performance of asphalt-rubber seal coats does not appear related to fundamental material characteristics, but rather, to construction practices."

Given that asphalt-rubber can be successfully constructed, the issues become the long-term pavement performance and the cost effectiveness of using asphalt-rubber membranes as an alternative highway construction material.

DEFINITIONS

The development of a specialized material carries with it specialized terminology. For consistency, the following definitions are adopted from work published by Schnormeier (Ref. 6):

Asphalt-Rubber - A mixture of asphalt and rubber produced by either the McDonald Process or the Arizona Refinery Process. The McDonald process was established in 1968 and combines hot asphalt cement, AR-1000, with 25% ground rubber to establish the reaction and diluted with kerosene for application. The Arizona Refining Process was established in 1975 and consists of hot asphalt cement, AR-4000 or 8000 mixed with 18 to 22% ground rubber to establish the reaction and diluted with an oil extender for ease of application.

Asphalt-Rubber Chip Seal - The application of hot asphalt-rubber followed by an application of hot precoated 1/4 inch nominal or 3/8 inch nominal aggregate.

Standard or Conventional Chip Seal - The application of hot asphalt cement, AR-4000 or AR-8000, followed by an application of hot precoated 1/4 inch nominal aggregate.

Flush Seal - The application of emulsified asphalt mixed 50-50 with water and applied at 0.1 to 0.2 gallon per square yard.

Stress Absorbing Membrane (SAM) - The application of a hot asphalt-rubber seal coat to a stressed surface.

Stress Absorbing Membrane Inter layer (SAMI) - The application of a hot asphalt-rubber chip seal to a stressed surface followed by an asphaltic concrete overlay.

Mini SAMI - The application of a hot asphalt-rubber chip seal to a surface followed by the application of a conventional chip seal.

Texture - The exposure of the aggregate to develop skid resistance.

Reflective Crack - Any crack that has passed through the asphalt rubber seal.

In addition, asphalt-rubber has been used for the resurfacing of portland cement concrete and asphalt concrete pavements where reflection cracking through overlays is a particularly serious problem.

Three-layer system - An application of a hot asphalt rubber seal coat between layers of asphalt concrete friction courses on pavements. The asphalt concrete friction coarse may be either 5/8 or 1/2 inch thick and the hot asphalt rubber seal coat is 3/8 inch thick. (The three-layer system was not evaluated during this research).

Finally, asphalt-rubber can be used as the binder material in asphalt concrete. Several pavement sections have been constructed with asphalt concrete friction courses using asphalt-rubber as the binder.

In all cases, the term asphalt-rubber is reserved to describe a material where there is a chemical reaction between the asphalt and the rubber. This excludes materials where rubber is used as a mineral filler or aggregate in an asphalt concrete mix.

ASPHALT-RUBBER MATERIALS

Asphalt-rubber contains three primary ingredients:

asphalt

rubber

diluent

Originally, the diluent was not used in the mix; however the high viscosity of the asphalt-rubber led to field construction problems so diluent was added to reduce the viscosity of the mix. The specific types and quantities of each ingredient are controlled by specifications and the producers. There has been an evolution of the materials over the years.

According to Schnormeier (Ref. 6), there are two basic types of asphalt-rubber, produced by either the McDonald process or the Arizona Refining Company, ARCO, process. The McDonald process uses AR-1000 asphalt cement, 25 percent ground rubber and diluted with kerosene (Ref. 6). Sahuaro Petroleum and Asphalt Company produced materials using the McDonald process. The ARCO process uses either AR4000 or AR8000 asphalt cement mixed with 18 to 22 percent ground rubber diluted with an extender oil (Ref. 6). Schnormeier does not define the properties of either the crumb rubber or the extender oil and does not describe the mixing process. Specifications for these materials are available from the industry.

Morris (Ref. 2) described the original patented McDonald process as one part ground tire rubber, #16 to #25 mesh size added to three parts Los Angeles Basin 60 to 70 pen-grade asphalt, reacted together for 20 minutes at a temperature of 375°F. Initially, the mix was applied with a slurry machine, but problems were encountered with the quality control of the mix, material thickness and the danger of handling asphalt at 450°F in a slurry machine. Five to seven percent kerosene was added to the mix in 1971 to reduce the viscosity for construction. Morris (Ref. 2) also reports the asphalt cement was changed from 60 to 70 pen to 120 to 150 pen-grade but does not identify the date of the change, although the report infers the data of change was 1971.

In 1982, Rosner and Chehovits (Ref. 7) published the results of a four year research project on the chemical and physical properties of asphalt-rubber mixtures. During this project, laboratory samples were prepared in accordance with both the McDonald and ARCO process. According to Rosner and Chehovits, the Sahuaro-McDonald process uses AR-1000 asphalt cement with 25 percent ground tire rubber and a diluent oil. AR-1000 has a penetration of approximately 200 to 300 so it is considerably softer than the asphalt identified by Morris. Rosner and Chehovits state the Sahuaro-McDonald process uses Altos Rubber and Reclaiming Co. product TP044 composed of ambient grind tread peel rubber sized between #8 and #30 mesh screens. The gradation used by Rosner and Chehovits was:

Sieve Size	Percent Passing
#8	100
#16	83
#30	7
#50	1
#100	0.5
#200	0

Rosner and Chehovits used kerosene produced by Chevron, product 410-H, as the diluent oil.

According to Rosner and Chehovits, the ARCO process uses AR 4000 asphalt cement with 2 percent Califlux GP extender oil manufactured by Golden Bear Division of Witco Chemical Corporation. Rubber produced by U.S. Rubber Reclaiming, product GT 274 is added to the asphalt cement at a rate of 20 percent. The material is a blend of 40 percent powdered reclaimed (devulcanized) rubber and 60 percent ambient ground vulcanized rubber which contains a high natural rubber content. The particle size is mostly between a #16 and #100 mesh sieves. The specific gradation is:

Sieve Size	Percent Passing
#8	100
#16	98
#30	76
#50	23
#100	8
#200	0

Rosner and Chehovits indicate that diluent oils are not routinely used with the ARCO process. The 2 percent Califlux GP extender oil used in the process does reduce the viscosity of the AR-4000 asphalt cement, but at this concentration the viscosity is still much greater than the viscosity of the AR-1000 asphalt cement used in the Sahuaro-McDonald process.

Shuler et al. (Ref. 8) noted the learning process associated with new products has influenced the performance of asphalt-rubber seal coats. Preblending the asphalt-rubber begun in 1979 appears to have improved the performance of SAM treatments. This further demonstrates the evolutionary nature of the technology of producing new materials and using them in pavement construction.

FUNCTION OF RUBBER IN ASPHALT-RUBBER

There are basically two reasons for adding rubber to asphalt:

1. improve binder properties
2. dispose of a waste material.

The primary reason for using asphalt rubber is to improve the binder properties, is more difficult to identify and quantify. According to Green and Tolonen (Ref. 9) the performance of asphalt concrete pavements has been limited by the tendency of the asphalt cement to become brittle with age. When the asphalt cement cannot deform without fracturing, it cannot hold the aggregate in place on the roadway. The addition of rubber to asphalt is an attempt to extend the life of an asphalt cement by imparting rubber-like properties to the asphalt. Oliver (Ref. 10) supports the concept that retention of chips in hot weather is an advantage of asphalt rubber. In addition, Oliver (Ref. 10) lists the sealing of cracks and reduction of reflection cracks as primary advantages of asphalt-rubber binders. Shuler, Pavlovich, and Epps (Ref. 5) state the use of rubber is primarily an attempt to input additional elasticity to the pavement material. In addition, asphalt-rubber has a lower temperature susceptibility than neat asphalt as shown in Figure 1 (Ref. 2).

In Schnormeier's most recent evaluation of asphalt-rubber projects in Phoenix (Ref. 11), the ability of a hot asphalt-rubber membrane to seal underlying asphalt layers was recognized. Schnormeier studied the viscosity of asphalt samples recovered from runways and taxiways at the Phoenix Sky Harbor Airport. The taxiway pavement was conventional construction and the runway section had a SAM treatment. The results, shown in Figure 2, demonstrate a dramatic increase in the viscosity of the unsealed section. The viscosity of the asphalt under the SAM treatment was virtually unchanged after 13 years. Schnormeier states the ability of the asphalt-rubber to seal a pavement surface is "perhaps the most significant and surprising property" of asphalt-rubber. Although the application was different, ADOT had previously recognized the sealing ability of asphalt-rubber to prevent moisture migration (Ref. 12).

In summary, rubber in an asphalt-rubber mixture performing several functions:

1. improves bond between binder and aggregates
2. improves elasticity or ability of the binder to deform without fracture.
3. seal either an asphalt to prevent loss of volatiles, or a subgrade layer to prevent moisture movement.
4. reduces temperature susceptibility of the asphalt cement.

Figure 1. Temperature Susceptability of Asphalt-Rubber and Neat Asphalt

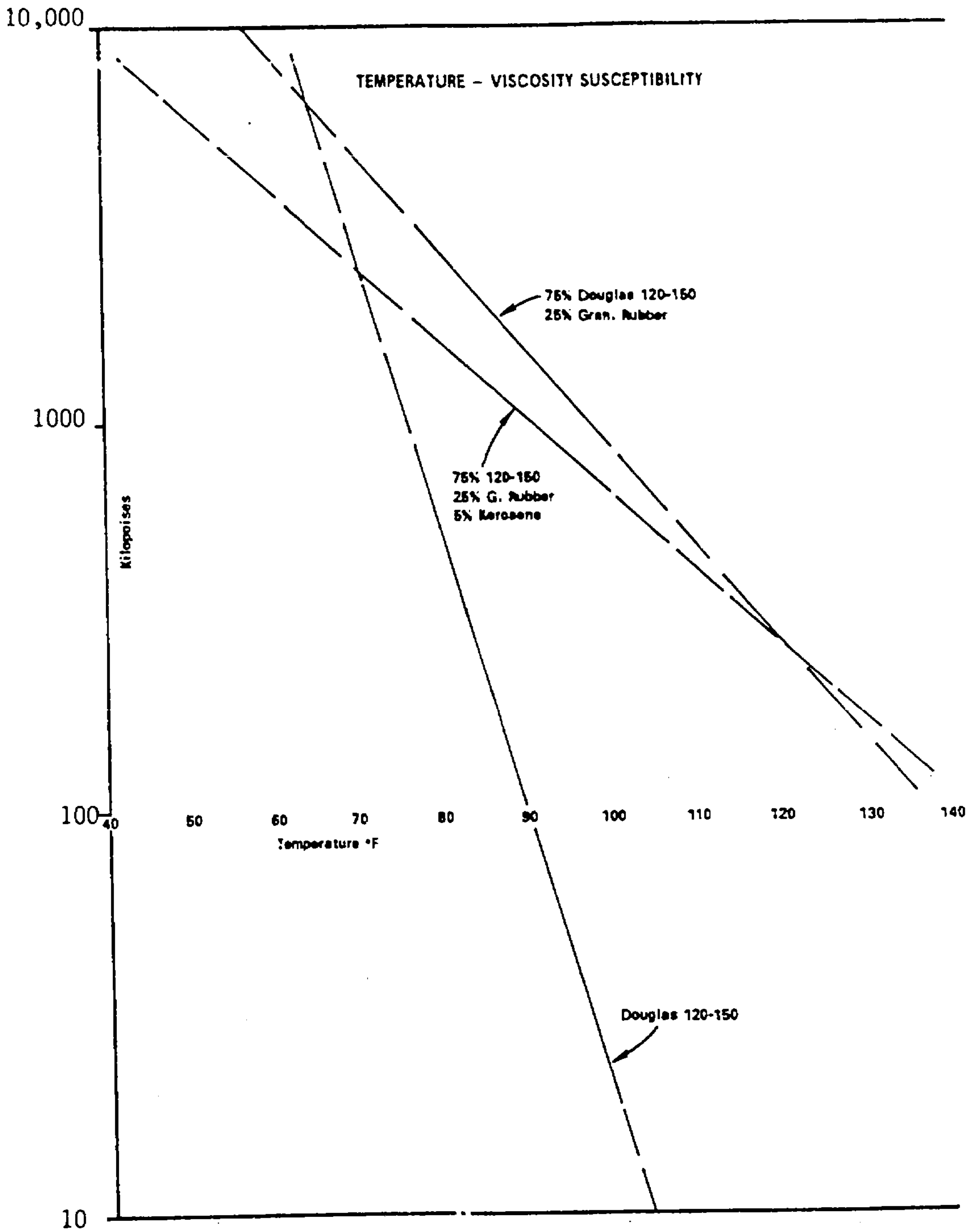
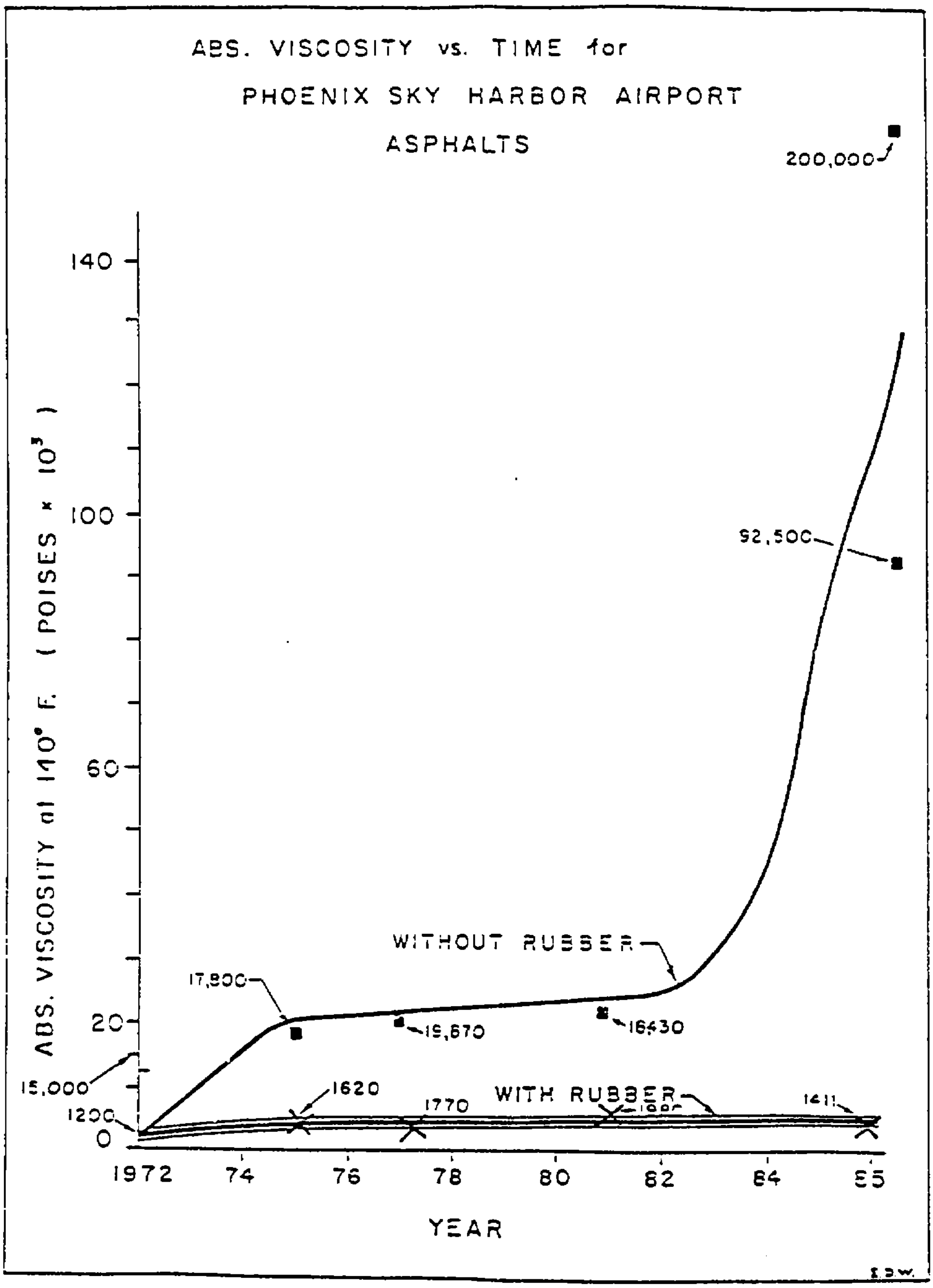


Figure 2. Absolute Viscosity vs Time for Phoenix Sky Harbor Airport Asphalts



The Environmental Protection Agency with the intent of disposing of old tires, has proposed "Guidelines for the Procurement of Asphaltic Materials for Construction and Rehabilitation of Paved Surfaces" (Ref. 13). Under the proposed rule, state highway agencies will be required to develop an affirmative procurement program to ensure the maximum use of asphalt materials containing ground rubber. Procuring agencies will be required to use asphalt materials containing the maximum amount of ground rubber possible in paved surface construction and rehabilitation whenever such use would be technically appropriate and economically feasible. Under the proposed rule, use of asphalt-rubber will be based on sound engineering and economic principles so the EPA proposed rule should not affect the current practices of ADOT.

OVERVIEW OF THE REPORT

The balance of this report reviews the research and performance of asphalt-rubber in ADOT projects Arizona. Chapter 2 reviews the research program performed or sponsored by ADOT. The chapter has two major sections, the laboratory research program and the research experimental projects constructed for field evaluation of asphalt-rubber. Chapter 3 is an evaluation of the asphalt-rubber projects which were constructed in the routine or normal construction cycle. In this chapter the characteristics of the sections, traffic loadings, and performance of both the SAM and SAMI sections are evaluated. Chapter 4 presents an analysis of the performance of conventional seal coats and overlay treatments. Economic analysis of asphalt-rubber and conventional treatments are presented in Chapter 5.

CHAPTER II ADOT ASPHALT-RUBBER RESEARCH

ADOT has performed and sponsored several research projects on the use of asphalt-rubber binders for stress absorbing membranes, stress absorbing membrane interlayers, and in the three layer system. Conceptually, one would desire a complete laboratory evaluation of a new material prior to using the material in a field application. However, the reality of research in the pavements area generally has concurrent activities in the field and laboratory.

The first asphalt-rubber activity executed by ADOT was the construction of test sections starting in 1967 (Ref. 4). The performance of the sections were monitored for several years before the department initiated a comprehensive research program into the properties of asphalt-rubber. The first laboratory research project was initiated in 1975 and completed in 1977 (Ref. 9). Since that time several projects have been completed on many aspects of the material behavior of asphalt-rubber.

Concurrent with the performance of the laboratory research, the department was constructing both research experimental projects and regular construction projects with asphalt-rubber membranes. In fact, the State Engineer ordered SAMIs be incorporated on all overlay projects of less than four inches during the 1975-76 fiscal year. (Mr. Gene Morris asserts this policy was only implemented on pavements with more than 20% cracking). As a result it was estimated Arizona would use nearly 10,000 tons of ground rubber in 1975-76 fiscal year (Ref. 3).

LABORATORY RESEARCH PROGRAM

The fundamental research on methods of blending asphalt and rubber were conducted by Charles McDonald. Material suppliers and construction contractors developed the equipment for commercially mixing and applying asphalt rubber. ADOT's research program began with a comprehensive evaluation of the chemical and physical properties of asphalt-rubber.

The first topic address in the ADOT laboratory research program was the basic material behavior of asphalt-rubber (Ref. 9). Due to the markedly different properties of asphalt-rubber versus neat asphalt cement, the conventional production control methods are not satisfactory for asphalt-rubber. The primary objective of the project was the development of test methods for asphalt-rubber production control.

Asphalt-rubber mixtures are highly viscoelastic; development of methods for evaluating the behavior of a material requires an understanding of the mechanical behavior of the material. According to Green and Tolonen (Ref. 9), asphalt-rubber has a higher modulus of stiffness and a higher viscosity than asphalt above 50°F but a lower modulus than asphalt below 50°F. The ultimate maximum stiffness of asphalt-rubber is one fifth of the asphalt value. Assuming equal tensile strength for both materials leads to the conclusion that in cold weather asphalt-rubber can undergo about five times the strain before rupture. This attribute of asphalt-rubber explains the superior performance, compared to asphalt, with respect to resistance to reflection cracking (Ref. 9).

The study of the viscoelastic properties of asphalt-rubber requires the use of a mechanical spectrograph which is too complicated for routine use in an asphalt control lab. A quality control test was developed which measures strain recovery using a sliding plate viscometer. Furthermore, the asphalt-rubber reaction continues after mixing so Green and Toloner recommend a procedure for rapidly cooling samples for transportation and storage so the properties measured in the lab accurately reflects the material placed in the field.

The second phase of the project on chemical and physical properties of asphalt-rubber mixtures addressed specifications and test procedures. Pavlovich, Shuler, and Rosner performed the research through Engineering Testing Laboratories (Ref. 14). The objective of the study was to develop test methods and specifications for the control of asphalt-rubber. In particular, the researchers studied the interaction between asphalt and reclaimed crumb rubber. All experiments in this research were performed on a blend of 75% AR-1000 and 25% crumb rubber, sized No. 16 to No. 25. Asphalt-rubber samples were manufactured at 350, 375, and 400°F with mixing times of 0.5, 1.0 and 2.0 hours. Several standard tests used for evaluating the quality of asphalt cement were performed to determine the best test for evaluating the quality of asphalt-rubber. The primary conclusion was the properties of asphalt-rubber are much more variable than asphalt cement when standard tests such as softening point and absolute viscosity are used for the material investigation. The force-ductility test was the only test capable of distinguishing the effect of reaction temperature and time.

Concurrently with the Engineering Testing Laboratory project, Dr. Jimenez at the University of Arizona performed a project for "Test Methods for Asphalt-Rubber" (Ref. 15). The goal of the Jimenez project was to develop test procedures related to reflection cracking; however, viscosity and ductility tests were performed to obtain comparative values for neat asphalt and asphalt-rubber. Jimenez tested viscosity using a falling coaxial cylinder viscometer, ductility with a modification of the standard AASHTO procedure, and horizontal and vertical shear tests. Jimenez concluded the falling coaxial cylinder viscometer test provided acceptable data and demonstrated the addition of rubber to asphalt significantly reduces the temperature-viscosity relationship of the material. At 140°F the viscosity of asphalt-rubber was 200 times greater than the viscosity of asphalt, but at 32°F the viscosity of asphalt-rubber was one sixth of the viscosity of neat asphalt. Ductility test indicated the asphalt-rubber was not significantly affected in the range of 77-33°F. The horizontal and vertical shear tests demonstrated the ability of asphalt-rubber to act as a stress membrane.

Phase III of the project on the "Chemical and Physical Properties of Asphalt Rubber Mixtures" was conducted by Rosner and Chehovitz at Western Technologies. The results of the research were presented in 6 volumes published in April of 1982. Separate volumes addressed the effects of:

1. rubber type, concentration and asphalt
2. asphalt characteristics
3. diluent
4. field versus laboratory prepared materials
5. temperature

The sixth volume is a summary of the research in Phase III. The following discussion was derived primarily from the Summary Report (Ref. 7).

A statistically designed experiment was performed to evaluate the effects on mixture properties of:

1. temperature
2. diluent
3. asphalt-rubber components
4. laboratory versus field produced mixtures

The research also addressed the applicability of methods for testing asphalt-rubber.

The effects of rubber type, concentration, and asphalt was tested using six types of rubber, four percentages of rubber and two asphalt types. Two samples were tested for each combination of factors and levels. Each material combination was tested six ways:

1. Absolute viscosity (140^{O}F)
2. Schweyer Reheometer (39.2^{O}F)
3. Force-ductility (39.2^{O}F)
4. Sliding Plate Microviscometer (32^{O}F)
5. Viscosity during mixing (375^{O}F) using the Arizona Torque-Fork
6. Viscosity during mixing (375^{O}F) using Haake Rotational viscometer.

Two general conclusions could be derived from these tests:

1. Asphalt-rubber properties, or at least the test results, are highly variable.
2. The type of rubber, concentration of rubber, and asphalt type, and all two way and three way interactions were significant at the 0.05 level in the vast majority of cases.

Once the data base was established, the authors further investigated the specific effect of asphalt type on the asphalt-rubber mixture properties. Conceptually, the experiment was designed to test four asphalt types. However, after examining the report, one finds the tests were performed on an AR1000 and blends of AR4000 and Califlux GP extender oil at 2, 6, and 15 percent by the weight of the asphalt cement.

The 2 percent Califlux GP is used in the ARCO process. The 15 percent concentration reduced the viscosity of the AR4000 to be similar to AR1000. The 6 percent concentration was selected as a midpoint between the two extremes.

The experiment with each of the asphalt "types" were performed with two types of rubber at three quantity levels each. The physical properties of the asphalt-rubber mixes were evaluated with the same six tests as in the previous experiment. The analysis of the test results demonstrated significant differences in the properties of the mixes with the exception of the viscosity measured with the Schweyer rheometer.

Diluent is added to asphalt-rubber to reduce the viscosity, thereby allowing spray application through a modified distributor truck. Two factors were examined during the experiment, the concentration of the diluent and the curing time at 140°F. AR-1000 and Altos rubber TP044 were used in the diluent oil experiment in a ratio of 3 to 1. The concentration levels were 0, 2, 4, and 6 percent diluent and curing times of 0, 1, 4, 24, and 168 hours. The significant effects are shown in Figure 3. Ring and ball softening point decreased at higher concentrations of diluent and increased curing time decreases the softening effect of the diluent. Increased diluent concentration increases the apparent viscosity at 39.2°F as measured using the Schweyer rheometer, but the Schweyer viscosity is not influenced by cure

Figure 3. Summary of significant effects of diluent concentration and curing time experiment

TEST PARAMETER / EFFECT	C	T	CT
Softening Point	Y	Y	Y
SCHWEYER RHEOMETER (39.2F)			
Constant(C), G-tube	Y	-	-
Constant(C), F-tube	-	-	-
App. Viscosity, G-tube	Y	-	-
App. Viscosity, F-tube	Y	-	-
FORCE DUCTILITY (39.2F)			
Load at Failure	Y	Y	Y
Elongation at Failure	-	-	-
Eng. Stress at Failure	Y	Y	Y
Eng. Strain at Failure	-	-	-
True Stress at Failure	Y	Y	Y
True Strain at Failure	-	-	-
Eng. Creep Compliance	Y	Y	Y
True Creep Compliance	Y	Y	Y
Max. True Creep Compliance	Y	Y	Y
Time to Max. T. Creep Compl.	Y	Y	Y

*Note: Y = significant at the 0.05 level

- = not significant at the 0.05 level

C = diluent concentration

T = cure time

time. As expected, increased diluent concentration lowers load and stresses at failure in the force-ductility test.

The effect of temperature on the properties of asphalt-rubber verified the expected relationships between temperature, viscosity parameters, and elongation. In addition, there was an interaction between temperature and percent rubber, and temperature and asphalt type. This indicates the temperature susceptibility of asphalt-rubber varies with rubber content and asphalt type.

There was a small experiment to evaluate the characteristics of field mixed asphalt-rubbers. Two manufacturers produced a total of eight samples which varied with respect to asphalt type, rubber type, rubber content, diluent concentration, etc. This experiment found significantly different properties between the suppliers, but this conclusion was confounded by the lack of a common asphalt-rubber mixture between the two suppliers.

Implementation of the laboratory testing requires a correlation between the field laboratory asphalt-rubber mixes. Asphalt-rubber mixtures were obtained from the Buckeye-Liberty test project and compared to laboratory mixtures prepared to the same specification. The components of the mixes are shown in Table 1. The results of the tests demonstrate field produced mixtures are significantly softer than the lab produced mixtures. This conclusion was true for the mixtures from both manufacturers and for the various combinations of mixtures.

The results of this research project on the properties of asphalt rubber may be summarized as:

1. The force-ductility test is the most sensitive test and has the lowest variability of the procedures evaluated for

TABLE 1 COMPONENTS OF LABORATORY AND FIELD ASPHALT-RUBBER MIXTURES

Component	Sample		
	8NC	3A	2A
Asphalt Type	AR1000	AR1000	AR4000
Asphalt Source	Edgington	Edgington	Powerene
Rubber Type	TP044	TP044	GT274
% Rubber	25	25	20
% Diluent or Extender	0	4	2
Reaction Time (hr)	1.5	6.5	4,24,166
Supplier	1	1	2

measuring the properties of asphalt rubber. Force-ductility test parameters may be used to specify physical properties of asphalt rubber.

2. The physical properties of asphalt rubber depend on:

   a. type of rubber

   b. concentration of rubber

   c. asphalt grade

   d. test temperature

   e. diluent concentration

   f. curing time

3. Asphalt-rubber mixtures formulated with high natural rubber content devulcanized crumb rubber were more temperature susceptible than mixtures formulated with ambient grind crumb rubber.

4. The properties of field-produced asphalt-rubber differ widely.

5. Lab produced asphalt-rubber mixtures are significantly stiffer than comparable field produced mixtures.

It should be noted the test procedure findings of Rosner and Chehovits are in conflict with the findings of Green and Tolonen. Rosner and Chehovits state, " ... absolute viscosity test procedures with asphalt rubber materials yield results which had high degrees of variability. Variability, in many cases, was high enough to mask differences in mixture characteristics which were noted with force-ductility and sliding plate microviscometer testing." On the other hand Green and Tolonen state, "The absolute viscosity at 60°C (140°F), 10 cm

Hg, should be used to determine the viscosity of asphalt-rubber and asphalt-rubber-kerosene mixtures. The viscosity of the mixture is closely related to the handling and application of the mixture and may relate to performance after the field studies are performed."

The major thrust of the ADOT research program was conducted in the late 1970's and early 1980's. The asphalt-rubber industry has continued the development of the product and report low variability of the product and good repeatability. Table 2 was compiled from lab reports by CRAFTCO Inc. and International Surfacing Inc. The columns labeled "LAB" are for materials prepared in the laboratory, and the "JOB" columns are for materials produced in the field. The last 12 columns are for field materials prepared at different times with the same formula. These results show less variability than the ADOT sponsored research.

FIELD RESEARCH PROGRAM

ADOT's evaluation of asphalt-rubber in the field actually preceded the laboratory experiments. The first asphalt-rubber section constructed by ADOT was on East Van Buren, US-80, near downtown Phoenix (Ref. 2). A section two blocks long was constructed in 1967. A slurry machine was used to place the asphalt-rubber. The second section was placed in 1968 on the frontage roads and access ramps of I-17 at Van Buren. This section was removed in 1987. This application used a distributor truck which was more successful than the slurry machine, but construction problems still persisted. Notably, the viscosity of the asphalt-rubber was too great to allow uniform spraying of the material with a conventional distributor truck. Although construction problems were encountered these first two sections, evaluation of the sections after two years demonstrated the asphalt-rubber was performing well and

TABLE 2 QUALITY CONTROL DATA FROM INDUSTRY

			Viscosity @ 350°F	Penetration @ 77°F	Resilience % @ 77°F	Ductility @ 77°F	Softening Point °F
Sacramento	LAB		3500	26	36	--	152
California	JOB		4000	28	44	26	146
San Antioni	LAB		3200	41	31	--	137
Texas	JOB		2000	47	22	20	140
California	LAB[1]		1930	53	30	--[2]	162
	JOB	A	2200	71	20	43	132
		B	3300	54	27	31	142
		C	2000	58	30	33	140
		D	2500	51	32	27	140
		E	1500[3]	45	31	26	144
		F	2500	57	26	38	142
		G	2500	52	29	38	146
		H	2000[3]	71	27	--	148
		I	1600[4]	55	30	34.5	144
		J	2100[4]	57	33	34	147
		K	2000[3]	44	29	33	148
		L	1500	47	27	36	150

1. Data for 90 min. mixing and viscosity @ 365°F
2. Ductility at 120 min. mixing was 31.5
3. Viscosity measured @ 375°F
4. Viscosity measured @ 370°F

further experiments were warranted. The sections performed for 21 years and were removed for reconstruction of the ramp, not due to failure of the SAM.

In the Spring of 1971, ADOT participated in a National Experimental and Evaluation Project. A 13-mile test section, with 26 experimental features, was constructed on I40 near Minnetonka (Ref. 16). The project included one SAM and two SAMI sections. The final report on this project was prepared four years after construction. The asphalt rubber sections were performing well at the time of the report. The sections were re-evaluated in 1979 and were performing well (Ref. 17).

In June 1972, a SAM was placed on US-60, milepost 85.5 to 92.9 (Ref. 18). The highway was serving as a major truck route to California since Interstate 10 was not open at the time. The pavement was badly deteriorated with fatigue and thermal cracks. A thick overlay was planned but funds were not available so the SAM was placed instead. After three years, the fatigue cracking had not reflected through the surface although there was minor thermal cracking. In 1975, a 0.5 inch ACFC was placed on the surface to improve ride quality. The condition of the pavement was surveyed in 1980 and was in good condition. The pavement has not been overlaid or reconstructed as of 1985.

In 1972, a ten mile section was placed on U.S. 89 north of Flagstaff (Ref. 3). The pavement had severe alligator cracking prior to the SAMI treatment. The objective of placing the SAM was to delay the need for reconstruction for 18 months. The SAMI was reported to have completely controlled reflection cracking as of 1976.

In 1975, a SAMI was placed on I 40 between mile posts 318.8 to 330 (Ref. 18). The previous year a conventional section was placed from mile post 307.2 to 318.8 which served as a control section. The control section developed shrinkage type reflection cracks after one year and fatigue type reflection cracks in the second year. Roughness was increasing at a rate that would make the roughness unacceptable in 16 years. In comparison, the SAMI section did not have reflection cracks after four years and the roughness was increasing at about one half the rate of the control section. Furthermore, the maintenance cost on the SAMI was $22/mile/year versus $622/mile/year for the control section.

The success of these projects resulted in expanded use of asphalt-rubber by ADOT. A total of 37 research projects were constructed using asphalt-rubber. The features of the 25 active projects are shown in Tables 3, 4, and 5 for sections in good condition, sections with distress, and sections where at least part of the project has been overlaid, seal coated, or reconstructed, respectively.

Many of the REP sections were evaluated by ATRC staff engineers in 1985. Visual condition surveys were performed and photos were taken of the sections. However, the condition survey performed in 1985 was too informal to allow conclusions to be developed on the performance of the sections. To overcome this problem, the pavement rating manual used in the PAVER system (Ref. 19) was obtained and staff were trained in the performance of this condition survey method. This procedure should be used in all future evaluations of the pavement research sections. Even though the procedure is time consuming, and therefore expensive, the quality of the data obtained warrants the use of this method for research. The survey procedure is summarized in Appendix A. Figure 4 shows the data collection form. The method was used for the evaluation of one research experimental project.

TABLE 3 SUMMARY OF ASPHALT-RUBBER REP SECTIONS IN GOOD CONDITION

PIN NO.	PROJECT NO.	TYPE	PROJECT NAME OR ROUTE NO.	MILEPOST	DATE CONSTRUCTED	TYPE OF WORK	STATUS AND REMARKS
R24	IR-17-1(124)	REP 7904	7th St-Buckeye Rd.	196.0-198.81	1979	3 Layer System over PCCP 500 ft. section.	Currently evaluating. Last eval. 7/21/85
R25	IR-17-1(158)	EP 8501	JCT I-10-Buckeye Rd.	194.8-198.8	1985	Devulcanized asphalt-rubber overlay	Evaluated 7/21/85
B104	S-581-501	REP	SR 66	61.34-61.86	1979	EB Control Section + AR 1000, WB SAMI	Evaluated 7/24/85
B105	S-243-903	REP	SR 68 Davis Dam-Kingman	0.0-8.15 15.62-27.22	1976	2 Test Sections Rubber Products	Evaluated 7/23/85
B108	S-568-901	REP 7802	Ashfork-Flagstaff Jct. I-40 and U.S. 89A	191.8-195.40	1978	Asphalt Rubber Seal Coat.	Evaluated 8/7/85
B110	S-577-904	REP	SR 92	340.5-345.0	1982	Asphalt Rubber ACFC	Evaluated 6/26/85
B111	F-058-1-502	REP	SR 169	10.0-15.0	1982	3 Test Sections: 1-Treated Subgrade, 2-Experimental SAMI, 3-2in. AC on Subgrade	Evaluated 7/25/85
B125	F-016-1-915	REP 8102	US 80 Mule Pass Tunnel-Bisbee Underpass	339.35-342.80	1982	Seal Coat Asphalt-Rubber Mix ACFC	Evaluated 6/26/85
G162	I-40-4(70)	REP	Holbrook Int.	283.6-290.11	1981	Expansive Clay Control-Asphalt Rubber on Cutoff Walls	Evaluated 7/9/85

TABLE 4 SUMMARY OF ASPHALT-RUBBER REP SECTIONS WITH DISTRESS

PIN NO.	PROJECT NO.	TYPE	PROJECT NAME OR ROUTE NO.	MILEPOST	DATE CONSTRUCTED	TYPE OF WORK	STATUS AND REMARKS
B109	I-IR-17-2(78)	REP 7702	Yavapai County Line-Munds Park TI	313.0-323.0	1977	SAMI Overlay and ACFC (Salt River Agr.)	All test sections are showing distress, 8/7/85 Needs final eval.
B112	F-071-1-503	REP	US 666	344.6-356.35	1979	2 in. overlay (504 Job SAMI+ Overlay with Blended Asphalt)	Show signs of failure, 7/10/85
B116	F-039-1-912	REP 8103	Jct. SR 68-Kingman	67.08-71.40	1981	Asphalt Rubber ACFC	Poor Performance, 7/23/85
B118	S-210-504	REP 7604	Snowball Road-Kindrick Park.	222.8-235.36	1982	SAMI	Severe flushing & Raveling, 8/7/85
B120	I-17-2(48)	REP	I-17	286.2-291.6	1980	Rubberized membrane seal	Severe flushing, unstable mix. Scheduled to be rehabed in 1987.
B121	S-371-924	REP 7801	Buckeye-Liberty	164.0-172.0	1979	Various thin overlay sections to control reflective cracking	Portions have been overlayed with skin patches. Final report should be written.
B123	F-022-2-515	REP 8002	Beardsley Canal-Agua Fria.	138.0-146.16	1981	SAMI, ACFC, Blended Asphalt Test Sections	Recent flush coat, 7/23/85
B119	F-053-1-926	REP 8001	Beeline Highway Forest Boundary-Sycamore Creek	193.7-211.78	1975	Asphalt Rubber	Some Sections Performing Well 7/87

TABLE 5 SUMMARY OF ASPHALT-RUBBER REP SECTIONS WHICH HAVE BEEN COVERED WITH SEAL COAT OR OVERLAY OR RECONSTRUCTED

PIN NO.	PROJECT NO.	TYPE	PROJECT NAME OR ROUTE NO.	MILEPOST	DATE CONSTRUCTED	TYPE OF WORK	STATUS AND REMARKS
R28	I-17-1-952	REP	I-17 SB @ Bell Rd.	213.3-213.41	1974	Various ACFC Over PCCP	Overlay has been overlayed
R30	F-045-1-919	REP 7603	Mesa Underpass-Apache Blvd.	173.87-174.26	1977	Asphalt-Rubber Flush In, Rubberized ACFC over PCCP.	Rebuilt for geometrics
Y51	F-026-2-910	REP 7701	Springerville-New Mexico State-line	388.71-401.87	1978	Heater Scarification vs. asphalt-rubber.	Project was overlayed in 1985, F-026-2(7). Data is inconclusive but economic data is available. Asphalt-rubber over expansive soil
B102	F-022-1-910	REP 7707	US 60 Aguila-East	85.5-93.0	1977	Rubber Asphalt and ACFC-SAMI	Control Section is to be Removed during Constr. of S.R.71 Interchange Performing well 7/85
B103	FLH-033-1(10)	REP	SR 64	282.2-285.67	1982	8" CTB+SAMI+1" ACFC	Future 2" AC shown on plans are now in place.
R27	I-40-4-925	REP 7703	E. Flagstaff TI-East (WB)	202.79-203.97	1980	Six PCCP Overlays: 1)SAMI-ARCO Rubber 2)Three Layer 3)Three Layer 4)SAM 5)SAM 6)Overlay Sawed at Joints	Final Report Needs to be written.
B115	S-210-909	REP 7706	Flagstaff N.City Limits-Snowbowl Rd.	216.9-222.9	1977	7 Sections of SAMS and SAMI's	The first 4 sections have been chip sealed, 8/7/75
B135	S-203-907 S-203-906	REP	US 666	315.72-322.24	1976	SAMI	

Figure 4. Pavement Condition Evaluation Form

Highway ____ Lane ______ Milepost _________

Section _____ Sample unit ______

Observer ________ Recorder _________ Date ______

1. alligator cracking sf
2. bleeding sf
3. block cracking sf
4. bumps and sags lf
5. corrugations sf
6. depressions sf
7. edge cracking lf
8. joint reflec. crack lf
9. lane/shoulder drop lf
10. long. & trans. crack lf
11. patch sf
12. polished aggregates sf
13. potholes #
14. RR cross sf
15. rutting sf
16. shoving sf
17. slippage sf
18. swell sf
19. weathering & raveling sf

type of distress

rutting						
sum						
low						
medium						
high						

In 1975 an eight mile test section was constructed on state route 87 for evaluating several different applications of asphalt and rubber against the performance of a control section. Project F-053-1-926, commonly known as the Beeline Highway test section, was constructed to evaluate the three-layer system, long shard rubber, rubber in the place of mineral filler, and asphalt-rubber as a binder material. Figure 5 shows the layout of the test sections. There is not a concise report of the design of each of the sections. However, the properties of the sections were determined based on three memos in the project correspondence file:

1. From Morris to Lyon on 21 March 1975
2. From Morris to Livesay on 1 April 1975
3. From Lansdon to Morris on 1 August 1975 (post construction)

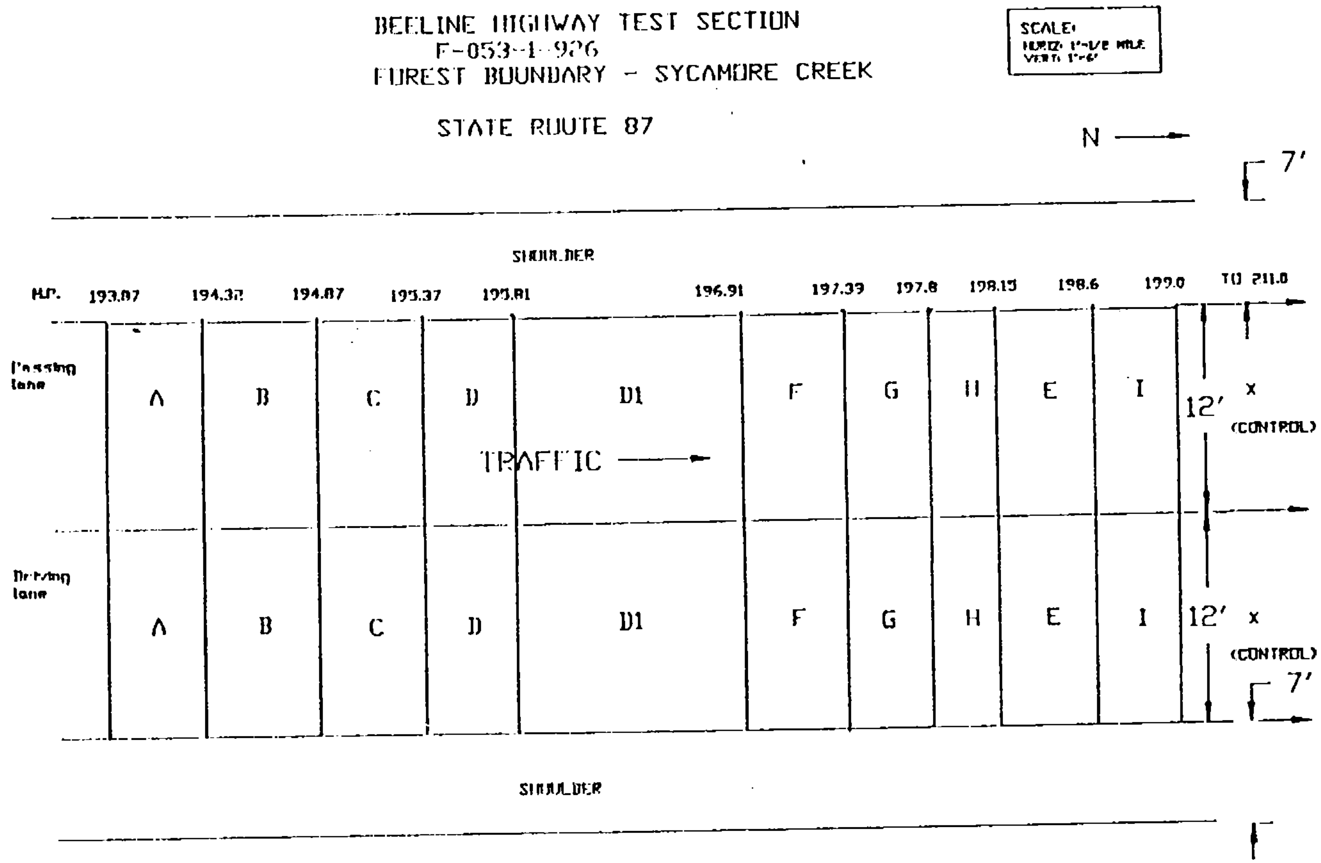
There is some conflicting information in three memos as the features of the sections were changed during the project development and construction phases. The following summary is based on the most recent memo when there was a data conflict.

Section A - Atlos vulcanized rubber grade TP044, number 16 mesh size, was used as a mineral filler at 2-1/2 percent rubber by total weight of the mix. The asphalt cement was AR-1000 at 8 percent asphalt content.

Section B - Same as Section A except the asphalt content was 7 percent and a 0.12 gsy petroleum resin flush coat was sprayed two days after the section was constructed.

Section C - U.S. Rubber Reclaiming Co. devulcanized rubber was used at 2-1/2 percent by weight of the mix. The gradation of the rubber was

Figure 5. Layout of the Beeline Highway Test Sections



not identified, but the product name was Flo-Mix. AR-1000 was used at 7 percent.

Section D - Atlos long shard vulcanized rubber, TP-2, was used at 2-1/2 percent by weight of mix. AR-1000 was used at 7 percent.

Section D1 - Same as Section D except long shard U.S. Rubber Reclaiming Co. rubber was used. Note, in all other cases, U.S. Rubber Reclaiming Co. products were identified as being devulcanized; presumably the rubber in this section was also devulcanized.

Section E - Altos long shard, TP-2, was used at 2 1/2 percent by weight of the mix. AR-1000 asphalt cement was used at 6 percent. A flush coat of 0.12 gsy petroleum resin was sprayed after construction.

Section F - This section was the first three-layer system. The first course was a 5/8 to 3/4 inch ACFC using CM1D aggregates and 4 percent AR-1000. Asphalt-rubber with 25 percent Altos rubber was sprayed on followed by 20 lb/sy of CM3 aggregates. The grade of asphalt cement and gradation of rubber was not identified; also the memos are mute on the use of a diluent. The type and quantity of rubber indicates this membrane was based on the Sahuaro-McDonald process. The top layer was a 5/8 inch ACFC with 6 percent asphalt cement. A flush coat of 0.12 gsy CSS-1h with latex was sprayed on the surface after construction.

Section G - This section was an experiment with asphalt-rubber as the binder in the asphalt concrete. The gradation of the aggregates was not identified. The binder was an AR-1000 with 25 percent vulcanized rubber. The binder content was 10.5 percent.

Section H - Same as Section G except 20 percent devulcanized rubber was used with an 8.5 percent binder content.

Section I - AR-4000 modified with 5 percent Dutrex was used at 6 percent binder content. After construction, the surface was flushed with 0.12 gsy of CSS-1h with latex.

Control Section - AR-1000 was used with a 6 percent asphalt content. The gradation of the aggregate was not identified. A flush coat of 0.12 gsy of SS-1h was sprayed after construction. Mr. Gene Morris reports the original design of the control section was different from the design of the other test sections, creating a bias in the comparison of the sections. Also the test sections are between Phoenix and the Sahuaro Lake turn off whereas the control section is beyond the turn off. Thus, the test sections may be carrying more traffic than the control section.

Lansdon's construction report indicates all sections received a layer of blotter sand after the flush coat. The report also indicates a problem with tender mixes but the specific sections are not identified. An interview with Mr. Lansdon revealed that due to high ambient temperatures, several sections were flushed with water to improve their stability.

Sections D and D1 failed by 1979 and have been replaced. Section I was in excellent condition and little if any distress was observed. The condition survey was not performed.

The performance of the remaining sections, in terms of the PAVER pavement condition index, PCI, is given in Table 6. During the survey, 15 contiguous 100 ft. sample units were surveyed in the driving lane. The starting point for the survey was randomly selected.

The sections with long shard rubber failed to perform. Sections D and D1 were removed four years after construction. Section E is still

TABLE 6 SUMMARY OF PAVEMENT CONDITION INDEX VALUES FOR THE BEELINE HIGHWAY TEST SECTIONS

Sample Unit \ Section	Control[1]	A	B	C[1]	E[2]	F[1]	G[1]	H[1]
1	60	37	53	61	42	62	62	62
2	60	36	59	62	49	62	62	59.4
3	54	54	40	62	52.5	62	62	62.2
4	63	45	43	62	69.2	62	60	62.2
5	62	26	35	62	78	62	64	67
6	62	50	37	60	85.3	62	62	62.5
7	62	35	35	58	66.3	60	62	62
8	60	31	40	58	39.1	62	61	62
9	62	45	47	54	38	62	62	62
10	62	48	36	53	37.5	62	62	58
11	58	49	36	65	83.9	62	59	60
12	58	48	36	61		62	59	65
13	59	49	36	61		62	60	54
14	58	43	33	62		62	59	58
15	62	62	36	62		62	62	60
$\bar{x}$	60.1	43.9	40.1	60.2		61.9	60.9	61.3
σ	2.4	9.4	7.4	3.2		0.5	1.7	3.0

[1]each of these sections have about 0.4" rutting, without rutting PCI would be greater than 90 indicating excellent performance

[2]extensive patching and sealing prevented accurate evaluation

in service but patching and sealing of the surface is so extensive that an accurate distress survey could not be performed.

Sections A and B with 2 1/2 percent vulcanized rubber used as a mineral filler have not performed as well as the other sections. The PCI of these sections is approximately 20 points lower than the other sections.

The section with devulcanized rubber used as a mineral filler, Section C, is performing about the same as sections F, G, H, and the Control. Each of these sections has a PCI of approximately 60, which is in the good range of the PAVER scale. The rutting on the entire test pavement is a little more than 0.4 inches. This level of rutting results in a deduct value of 37. If rutting is not considered, the PCI's would be better than 90 for these sections, which is excellent.

Section C has a minor amount of longitudinal and transverse cracking, isolated areas of minor raveling and three small areas of low severity alligator cracking. Section F has several areas of low severity raveling and lane/shoulder drop off. (Lane/shoulder drop off is not a pavement distress per se so it should be excluded from the PCI calculation when comparing pavement performance. However, in this particular analysis, the level of severity was so low that it did not affect the results.) Section H has a minor amount of longitudinal and transverse cracking and some lane/shoulder drop off. The control section has a minor amount of raveling and longitudinal and transverse cracking.

If rutting is not considered, then the overall performance of Sections C, F, G, H and the Control is excellent. Devulcanized rubber used as a mineral filler has performed well, whereas the sections with vulcanized rubber used as mineral filler have failed. Long shard rubber sections have also failed. The three-layer system, and asphalt-rubber binders have performed well, but the performance of the control section is equal to the asphalt-rubber sections.

SUMMARY OF THE RESEARCH PROGRAM

ADOT has gained valuable information on the material properties of asphalt-rubber through the laboratory research program. However, the laboratory research program demonstrated high variability. The variability could be the result of either the properties of the asphalt-rubber or the test methods used for neat asphalt may not be appropriate for asphalt-rubber. Quality control data supplied by asphalt-rubber producers for recent projects indicates less variability than was found during the ADOT sponsored research. It would be prudent to reexamine the need for further laboratory research at this time, particularly with respect to verifying the results provided by the asphalt-rubber producers.

The field research program has not lived up to its potential due to the lack of standardized and documented data collection procedures. However, the potential exists for capturing the performance of the REP sections at this time. This required developing or adopting a systematic condition survey procedure for capturing the pavement distress information in detail. The PAVER pavement condition index procedure is recommended. This procedure should be adopted for all REP sections under study by ADOT. The application of this procedure to the evaluation of the Beeline Highway test section has quantified the performance of these sections.

CHAPTER III PERFORMANCE OF ASPHALT-RUBBER HIGHWAY SECTIONS

The pavement management system data base contains pavement construction, overlay and performance records for the ADOT network. This data base allows an analysis of the performance of asphalt-rubber sections constructed as part of the routine construction process. The pavement management data base does not distinguish between SAM's and SAMI's, however, the type of treatment can be determined by manual inspection of the construction sequence. Tables 7 and 8 summarize the construction history of the SAM and SAMI sections.

STRESS ABSORBING MEMBRANES CONSTRUCTION HISTORY

As shown in Table 7, the data on the SAM sections were identified with respect to route, direction and milepost. The year the SAM was placed, the age of the pavement when the SAM was placed, and the age of the membrane when the next treatment was placed were summarized along with comments.

SAM's were placed on nine interstate sections. Most of the sections were constructed in the mid 1970's; six of the sections were placed in 1974, two in 1975 and one in 1978. All of the membranes placed in 1974 and 1975 have been overlaid. The average life of the rubber membrane was just over 5 years on the interstates. The overlays ranged in thickness from 2" to 6". The asphalt-rubber was not removed. The overlays may have been either to reduce roughness or improve structural capacity. The asphalt-rubber is still in place and serving.

SAM's were placed on eleven state highway sections. The oldest section was placed in 1967 and was removed in 1983 for a life of 16 years. The most recent membrane was placed in 1981, and was removed in

TABLE 7 SAM SECTIONS CONSTRUCTION DATA

	ROUTE	DIR	MP	YR OF RM	AGE @ RM	AGE @ COVER OF RM	COMMENTS*
1	I10	E	316	74	14	2	2" overlay
2	I10	E	317-321	74	11	5	2 1/2 OL
3	I10	W	323-331	74	11	5	2 1/2 OL RE in 81
4	I40	E	259-264	75	17 (3)	4	~2" OL 3 years prior to the RM 6.0" OL in 79
5	I40	E	265-268	74	12 (5)	5	6.5 OL in 79
6	I40	E	269-272	74	8	7	5.5" OL in 81 FL at time of RM.
7	I40	E	278-283	75	9	6	5.5 OL in 81
8	I40	W	203	78	10	-- (7)	LC placed w/RM
9	I40	W	269-283	74	12	7	6" OL in 81
10	S68	E	3-8	75	29	--	SC in 69
11	S68	E	16-27	75	29	--	SC in 69
12	S71	N	86-90	72	22	5	SAMI used for OL
13	S87	N	177	67	16	16	RE in 83
14	S87	N	179-182	74	20	--	RM placed on 0.5" FC
15	S87	N	186-193	74	19	--	RM placed on 0.5" FC 2" OL in 85
16	S89L	N	549	81	2	3	RE in 84
17	S95	N	191-200	77	0	1	Used in new construction
18	S264	E	323-344	76	16	--	FL in 70
19	S264	E	456-465	75	13	10	OL in 85
20	S264	E	466-471	75	13	8	OL in 83 2.8"

TABLE 7 SAM SECTIONS CONSTRUCTION DATA (Cont'd)

	ROUTE	DIR	MP	YR OF RM	AGE @ RM	AGE @ COVER OF RM	COMMENTS*
21	U60	E	86-92	72	17	5	SAMI in 77
22	U60	E	93-98	73	18	5	FC IN 78
23	U60	E	99-106	73	21	5	FC in 78
24	U60	E	107	73	20	5	FC in 78
25	U60	E	343-345	74	22	5	2.5 OL in 79
26	U60	E	349-352	74	32	6	2.5 OL in 80
27	U60	E	396-401	78	16	7	FL in 69
28	U70	E	255-257	74	27	8	2" OL in 82
29	U70	E	258-259	74	34	9	Recycle in 83
30	U89	S	66-67	72	48	--	
31	U89	N	421-425	73	36	4	SC in 77
32	U89	N	426-430	73	36	4	SC in 77, 3" OL in 83
33	U160	E	312-322	76	11	--	SC in 70, OL in 85
34	U160	E	323-331	76	16	9	SC in 70, OL in 85
35	U160	E	332-340	75	14	10	SC in 70, OL in 85
36	U160	E	345-357	75	14	10	
37	U160	E	406-415	81	19	--	SC in 70
38	U163	N	396-416	77	19	--	
39	U180	W	221-222	77	31	--	2.5" AC overlay placed at time of RM
40	U180	W	236-250	76	17	--	SC in 71

*Lift abbreviations are defined in Table 9.

TABLE 8 SAMI SECTIONS CONSTRUCTION DATA

	ROUTE	DIR	MP	YR OF RM	AGE @ RM	STRUCTURE W/RM*	COMMENTS*
1	I17	N	313-322	77	11	1.5 AC, .5FC	Multi treatments before SAMI
2	I40	E	319-330	75	13	1.5 LC, 1.3AC	RM placed on LC
3	I40	E	343-353	79	29(12)	2" LC, 4.3" AC, .5FC	2" OL in 67 RE 2" & OL in 84
4	I40	E	354-359	75	13	1.8 LC, 1.3 AC, .5FC	RM on LC
5	I40	W	212-217	77	8	2.0 AC, 0.5 FC	
6	I40	W	343-347	79	13	2.0" LC, 4.0" AC,.5FC	RE 2" & OL in 84 Two SC prior to RM
7	I40	W	348-353	79	12	2.0" LC, 4.0" AC,.5FC	RE 2" & OL in 84 Two SC prior to RM
8	S64	E	283-285	82	--	8" CB, RM, 1.0" FC	Original pavement removed in 82.
9	S71	N	86-90	77	27	0.5 FC	RM alone in 72
10	S73	N	341-348	77	28	3.0 AC, 0.3 SC	SC in 72
11	S85	N	165-169	79	32	1.0 AC, 0.5 SC	
12	S85	N	170-	79	21	0.6 FC, 0.5 FC	RM put between two layers of FC
13	S87	S	241-246	76	18	2.5 AC, 0.5 FC	SC in 68
14	S87	S	248-251	77	21	3.0 AC	
15	S95	N	228-233	76	9	2.0 AC, .5 FC	1.0" FC in 80 in 67 pavement was 2" BS
16	S169	N	11-14	79	0	1.0 FC	RE 7.3" in 81
17	S260	N	361-368	77	17	1.5 AC, FC	OL in 82

TABLE 8 SAMI SECTIONS CONSTRUCTION DATA (Cont'd)

ROUTE		DIR	MP	YEAR of RM	AGE @ RM	STRUCTURE W/RM	COMMENTS
18	S264	E	441-447	79	17	1.5" AC, SC 0.3	RE 0.5"in 82 0.6 FC
19	S277	N	323-335	78	17	1.5 AC, FC	
20	S277S	N	322	77	15	1.5 AC	SC in 74
21	S504	E	466-469	76	15	1.5 AC	
22	U60	E	138-146	80	32	1.5 AC, 0.5 FC	Seals in 71,73,76
23	U60	E	189-190	82	29	2.0 AC, 0.5 FC	FC in 72
24	U60	E	336-339	79	33	1.5 AC, 0.5 FC	SC in 66
26	U66	E	56-61	78	10	1.5 AC, 0.5 FC	
27	U66	W	57	78	44	1.5 AC, 0.5 FC	
28	U66	W	58-61	78	44	1.5 AC, 0.5 FC	3.2" OL on Pavement in 70
29	U70	E	280-287	77	20	1.5 AC	SC in 66 78 - FC 80 - FC
30	U70	E	301-306	77	18	1.5 AC	
31	U89	N	451-457	76	39	1.5 AC, 0.5 FC	SC in 68
32	U89	N	467-470	80	18	1.5LC, 3.0 AC, 0.5 SC, FL	SC in 83
33	U89	N	471-476	83	22	2.0 LC, 2.0 AC, 0.5 SC	
34	U89	N	477	83	23	2.0 LC, 2.0 AC, 0.5 SC	

TABLE 8 SAMI SECTIONS CONSTRUCTION DATA (Cont'd)

	ROUTE	DIR	MP	YEAR OF RM	AGE @ RM	STRUCTURE W/RM	COMMENTS
35	U89	N	478	83	23	2.0 LC, 2.0 AC, SC	RM between LC and AC, SC in 72
36	U89	N	479-481	76	16	0.8 LC, 2.0 AC, SC	
37	U89	N	482-485	85	14	2.0 LC, 1.5 AC, SC	
38	U89	N	490-493	84	25	2.0 AC, 2.0 AC, SC	RM between two AC layers
39	U89	N	495-503	85	27	1.5 LC, 1.5 AC, SC	
40	U89	N	508-511	77	19	3.0 AC, 0.5 SC	FC in 80
41	U89	N	512-513	80	21	3.0 AC, 0.3 SC	SC in 67 & 70
42	U89	N	518-523	80	41	3.0 AC, FL	SC in 83; 3" OL in 59 SC in 70
43	U89A	N	318	80	52	3.0 AC, FL	SC in 79
44	U89A	N	319-331	80	46	3.0 AC, FL	SC in 79
45	U89A	N	345-348	76	40	2.0 AC, FL	Slurry Seal in 71
46	U89A	N	349	76	40	2.0 AC, FL	SC in 70
47	U89A	N	351-352	76	12	2.0 AC, FL	FC in 78
48	U89A	N	357-370	77	39	1.5 AC	SC in 70
49	U89A	N	609-610	82	42	8 CB, 2 AC, FC	Pavement was reconstructed
50	U160	N	465	77	17	1.5 AC	
51	U160	N	466-470	77	16	1.5 AC	Original pavement different than MP 465

TABLE 8 SAMI SECTIONS CONSTRUCTION DATA (Cont'd)

	ROUTE	DIR	MP	YEAR OF RM	AGE @ RM	STRUCTURE W/RM	COMMENTS
52	U180	W	217-219	77	31	3.0 AC, .5 FC	
53	U180	W	223-235	76	18	3.0 AC, SC, FL	SC in 71 SC in 84
54	U666	E	132-138	76	26	2.5 AC, SC	FC in 83
55	U666	E	316	76	30	2.5 AC, FL	
56	U666	E	317-322	76	29	2.5 AC, FL	
57	U666	E	357-368	78	29	1.5 AC	79 SC

*Lift abbreviations are defined in Table 9.

TABLE 9 KEY TO PAVEMENT LIFT ABBREVIATIONS

CODE	DESCRIPTION	CODE	DESCRIPTION
AB	AGGREGATE BASE	GV	GROOVE
AC	ASPHALTIC CONCRETE	HS	HEATER SCARIFICATION
AS	ACSC - ASPHALTIC CONCRETE SURFACE COURSE	LB	LIME TREATED BASE
B	BASE MATERIAL - AB,SM	LC	LEVELING COURSE - AC,AZMO
BB	BITUMINOUS TREATED BASE	LS	LIME SUBGRADE
BS	BITUMINOUS TREATED SURFACE	PC	CONCRETE
CB	CEMENT TREATED BASE	SC	SEAL COAT - COVER MATERIAL WITH EMULSIFIED ASPHALT
CS	CEMENT TREATED SUBGRADE	SM	SELECT MATERIAL
FB	FLY ASH BASE	SS	SUBGRADE SEAL
FC	ACFC - ASPHALTIC CONCRETE FRICTION COURSE	SR	SLURRY SEAL
FL	FLUSH COAT - FOG SEAL	RC	RECYCLED AC - ASPHALT REMOVE, REJUVENATED, REPLACED
FR	ACFC WITH ASPHALTIC RUBBER	RE	REMOVED EXISTING MATERIAL
FS	FLY ASH SUBGRADE	RM	RUBERIZED MEMBRANE (INTERLAYER OR SEAL COAT)
GR	GRIND	RO	RECYCLED AC OVERLAY
CF	CONSTRUCTION FABRIC	CL	LEAN CONCRETE BASE
RF	ROCK FILL		

1984. Other than these extremes, the bulk of the SAM application on state routes were in the mid 1970's. One section was placed in 1972, two in 1974, four in 1975, and one each in 1976 and 1977. There is no indication of resealing of six of the pavement sections. A friction course was placed on one section one year after the membrane was placed, which may have been planned or staged construction.

The SAM placed in 1967 was removed in 1983, thus, it provided a life of 16 years. The other SAM sections lasted three to eight years before they were overlaid or removed. The original pavement structures were from 13 to 29 years old when the SAMs were placed. So the pavements are now 25 to 40 years old. Based on this information, one would be satisfied with the life of the structure and the ability of the SAM to prolong pavement life.

SAM's were placed on 20 homogeneous sections of US routes in Arizona. The earliest use was in 1972 when two sections were treated. One of these sections received a SAMI in 1977 and the other section is still functioning. There was regular use of SAM's on projects from 1972 until 1978. The most recent SAM placement was in 1980. Six of the SAM sections on route U60 received either a friction course or overlay after 5 years. One section on U60 was overlaid after five years, two sections on U89 received a seal coat after four years of service. The two sections on U70 provided eight to nine years of service. One section was overlaid and the other was recycled. Three sections on U160 were overlaid in 1985. The balance of the SAM sections have not received any treatment since they were placed. In other words, 30 percent of the SAM's lasted 5 years, 28 percent of the sections served 8 to 10 years, and the rest of the SAM's are still in service after 9 to 12 years. Of these sections, in two cases the asphalt-rubber membrane was removed prior to the subsequent treatment. In all other cases the asphalt-rubber membrane is still part of the pavement structure.

STRESS ABSORBING MEMBRANE INTERLAYERS CONSTRUCTION HISTORY

SAMI's were used on seven interstate sections, 14 state highway sections and 36 US highway sections. There have been a variety of placements of the asphalt-rubber layer. In most cases, the membrane is placed directly on the existing pavement followed by a leveling up course, asphalt concrete, and a friction coarse as needed. In some cases the leveling up course was placed on the existing pavement followed by the membrane then the asphalt concrete.

The seven SAMI sections on interstates were constructed from 1975 to 1979. The three sections placed in 1979 on I-40 have been overlaid. Mr. Gene Morris, the ADOT State Research Engineer when the SAMI sections on I-40 were placed, stated during an interview that the asphalt concrete material used for the overlay of these sections had low stability and therefore excess rutting developed. The low stability was caused by using a blow sand for the fine aggregate, a light grade asphalt cement, and flushing the pavement with rejuvenator at the time of construction. Thus, failure of the surface layer of asphalt concrete required removal of the 2" of the surface and overlay. The asphalt-rubber membrane did not fail and is still in place. The other interstate sections are in service and have not received further treatment.

SAMI's were placed on 13 state routes from 1975 to 1979. A "mini SAMI," asphalt rubber membrane followed by a friction course, was placed in 1982. Two of the four SAMI's placed in 1979 were removed in 1981 and

1982. The SAMI placed on S169 at milepost 11 to 14 was an attempt to place an asphalt-rubber membrane directly on the subgrade then surface with a one-inch friction course. Mr. Morris reported during an interview that construction equipment tore up the asphalt-rubber membrane, leading to premature failure of the section. One section was overlaid after five years of service, and another section received a friction course after four years of service. The remaining 10 sections are still in service after nine to eleven years of service. The SAMI's appear to be providing good service. They were placed on pavements which were 15 to 32 years old at the time of the treatment. So apparently, the original pavements provided good service and the life was effectively extended by the SAMI's.

SAMI's were placed on 36 US routes from 1973 to 1984. Nine of the SAMI's have received either a seal coat or friction course. One of the sections received a seal coat after eight years, but the other eight sections received the surface dressing within the first four years after the SAMI was placed. One would have to expect some problem with the design or construction of the asphalt concrete or friction course surface layer when sealing is required in four years or less. Two SAMI's received a seal coat after one year. These did not have any treatment on the asphalt concrete at the time the SAMI was placed. A fog seal was used as the final dressing on all but one of the other SAMI sections which received a seal coat in four years. Although fog seals were used on some successful projects, the correlation of the fog seal with the need for a seal coat shortly after the SAMI was placed may indicate that fog seals are not an appropriate treatment for finishing a SAMI job.

The majority of SAMI sections are still in service. These range in age from 3 to 12 years old. Considering the total mileage of the SAMI sections and their age at this time, the performance appears very good. The sections which have been overlaid or removed represent 47 of the 252 miles that have been overlaid with a SAMI. In most of these cases the pavements have only received a friction course or seal coat. These treatments would be used to correct a deficiency in the surface layer rather than a failure of the asphalt-rubber membrane. The asphalt-rubber membrane has been removed on only 6 of the 252 miles. Thus, the SAMI appears to provide excellent performance.

TRAFFIC HISTORY ON THE ASPHALT-RUBBER SECTIONS

A computer print out of the traffic data for all ADOT routes was provided by the sponsor. The data for the asphalt rubber sections obtained from the computer print out are summarized on Tables 10 and 11 for the SAM and SAMI sections respectively.

For pavement performance evaluation, the cumulative equivalent single axle loads are required over the performance period of the pavement. The right two columns in Tables 10 and 11 show the cumulative ESAL's both before and after the SAM or SAMI. These columns were computed using the procedures recommended for the analysis of ADOT traffic data (Ref. 20).

In general the traffic data appear reasonable. However, there are a couple of sections with unusual growth factors. U89 between mile posts 66 to 67 has a zero traffic growth factor. Thus, the cumulative traffic is simply the annual traffic times the number of years in the analysis period. U70 between mileposts 255 to 257 has a negative growth factor, -0.3%. If one uses this traffic growth factor and projects

TABLE 10 TRAFFIC HISTORY OF SAM SECTIONS

ROUTE	DIR	MILEPOST BEG.	MILEPOST END	YEAR OF SAM	AGE @ SAM	TRAFFIC GROWTH	EQUIVALENT BASE YEAR (1000)	SINGLE AXLE LOAD BEFORE SAM (1000)	SINGLE AXLE LOAD AFTER SAM (1000)
I10	E	316	316	74	14	1.8	450	4789	4877
I10	E	317	321	74	11	1.9	426	3568	4594
I10	W	323	331	74	11	2.4	448	3552	4718
I40	E	259	264	75	17	5.9	422	3945	3622
I40	E	265	268	74	12	3.2	390	3106	3967
I40	E	269	272	74	8	3.2	384	2080	3906
I40	E	278	283	75	9	5.4	420	2200	3660
I40	W	203	203	78	10	2.0	301	2410	2220
I40	W	269	283	74	12	5.2	416	2840	3931
S68	E	23	8	75	29	7.2	4	55	31
S68	E	16	27	75	29	6.7	24	361	201
S71	N	86	90	72	22	3.1	3	36	30
S87	N	177	177	67	16	6.9	152	1068	2000
S87	N	179	182	74	20	7.3	34	340	302
S87	N	186	193	74	19	4.8	36	391	345
S89L	N	549	549	81	2	7.4	116	158	484
S95	N	191	200	77	0	5.3	28	0	206
S264	E	323	344	76	16	8.3	5	38	35
S264	E	456	465	75	13	9.1	49	305	387
S264	E	466	471	75	13	9.1	49	305	387
U60	E	86	92	72	17	1.8	80	997	998
U60	E	93	98	73	18	1.8	80	1064	933
U60	E	99	106	73	21	1.8	80	1228	933
U60	E	107	107	73	20	5.0	119	1314	1212
U60	E	343	345	74	22	4.2	43	558	421
U60	E	349	352	74	32	4.2	43	791	421
U60	E	396	401	78	16	2.5	12	142	87
U70	E	255	257	74	27	-0.3	26	764	318
U70	E	258	259	74	34	1.5	18	451	198
U89	S	66	67	72	48	0.0	144	6912	2016
U89	N	421	425	73	36	4.5	88	1750	912
U89	N	426	430	73	36	4.5	88	1750	912
U160	E	312	322	76	11	0.9	6	53	52
U160	E	323	331	76	16	0.9	6	76	52
U160	E	332	340	75	14	0.9	6	67	58
U160	E	345	357	75	14	0.9	6	67	58
U160	E	406	415	80	19	3.4	37	494	200
U163	N	396	416	77	19	1.1	5	78	42
U180	W	221	222	77	31	2.9	8	154	60
U180	W	236	250	76	17	1.3	3	40	27

TABLE 11 TRAFFIC HISTORY OF SAMI SECTIONS

ROUTE	DIR	MILEPOST BEG.	MILEPOST END	YEAR OF SAMI	AGE @ SAMI	TRAFFIC GROWTH	EQUIVALENT BASE (1000)	SINGLE AXLE LOAD BEFORE SAMI (1000)	SINGLE AXLE LOAD AFTER SAMI (1000)
I17	N	313	322	77	11	3.9	180	1325	1383
I40	E	319	330	75	13	4.0	408	3343	3728
I40	E	343	353	79	29	2.0	383	8248	2491
I40	E	354	359	75	13	1.9	381	3786	3793
I40	W	212	217	77	8	2.7	294	1762	2356
I40	W	343	347	79	13	2.0	383	3979	2491
I40	W	348	353	79	12	2.0	383	3693	2491
S64	E	283	285	82	0	4.7	3	0	11
S71	N	86	90	77	27	3	3	46	20
S73	N	341	348	77	28	6.2	20	308	143
S85	N	165	169	79	21	3.0	97	1434	611
S85	N	170	170	79	21	3.0	97	1434	611
S87	S	241	246	76	18	4.9	34	363	277
S87	N	248	257	77	21	5.1	34	423	251
S95	N	228	233	76	9	11.9	30	120	206
S169	N	11	14	79	0	7.6	6	0	36
S260	N	361	368	77	17	3.3	12	138	94
S264	E	441	447	79	17	4.6	22	242	132
S277	N	323	335	78	17	3.5	48	555	336
S277S	N	322	322	77	15	2.3	31	347	252
S504	E	466	469	76	15	4.4	20	186	166
U60	E	138	146	80	32	1.0	43	1151	249
U60	E	189	190	82	29	1.7	174	3995	668
U60	E	336	339	79	33	0.6	33	962	226
U66	E	56	61	78	10	0.8	78	706	603
U66	W	57	57	78	44	0.8	78	2839	603
U66	W	58	61	78	44	1.8	23	723	171
U70	E	280	287	77	20	1.9	21	319	174
U70	E	301	306	77	18	1.6	21	300	176
U89	N	451	457	76	39	4.5	88	1966	727
U89	N	467	470	80	18	1.7	45	658	255
U89	N	471	476	83	22	1.7	45	818	131
U89	N	477	477	83	23	1.7	45	851	131
U89	N	478	478	83	23	1.7	45	851	131
U89	N	479	481	76	16	1.7	45	562	414
U89	N	482	485	85	14				
U89	N	490	493	84	25	1.6	24	499	47
U89	N	495	503	85	27				
U89	N	508	511	77	19	4.4	26	307	196
U89	N	512	513	80	21	4.4	26	357	137
U89	N	518	523	80	41	4.4	26	647	137
U89A	N	318		80	52				
U89A	N	319	331	80	46	5.5	11	276	54

TABLE 11 TRAFFIC HISTORY OF SAMI SECTIONS (Cont'd)

ROUTE	DIR	MILEPOST BEG.END	YEAR OF SAMI	AGE @ SAMI	TRAFFIC GROWTH	EQUIVALENT BASE (1000)	SINGLE AXLE LOAD BEFORE SAMI (1000)	AFTER SAMI (1000)
U89A	N	345 348	76	40	4.9	14	314	114
U89A	N	349 349	76	40	3.9	30	710	253
U89A	N	351 352	78	12	3.9	30	245	207
U89A	N	357 370	77	39	4.9	11	244	82
U89A	N	609 610	82	42	0.5	12	452	47
U160	N	465 465	77	17	2.8	39	468	311
U160	N	466 470	77	16	3.7	22	233	170
U180	W	217 219	77	31	6.4	15	252	107
U180	W	223 235	76	18	4.5	6	70	53
U666	E	132 138	76	26	0.0	20	520	200
U666	E	316 316	76	30	4.3	26	462	216
U666	E	317 322	76	29	4.3	26	448	216
U666	E	357 368	78	29	5.2	7	115	45

backward to when the road was opened, one computes an annual ESAL of 29,400 when the road was opened versus 26,000 ESAL in 1986. Route S95 from milepost 228 to 233 has a growth rate of 11.9 percent which can result in traffic exceeding the capacity of the road in a relatively short time.

Although the traffic data appear to be reasonable, the exceptions noted above generate some concern for the validity of the remaining data. The development of mechanistic performance models requires knowledge of historical traffic loads, which is not currently being captured in the ADOT PMS database.

PERFORMANCE OF SAM AND SAMI HIGHWAY SECTIONS

The pavement management system data base contains historical data on cracking, roughness, and Mu-Meter values. The Mu-meter data was not analyzed for this report. Data were provided for each milepost of the asphalt-rubber sections and the means per year were computed for each of the sections. The cracking and roughness data are summarized in Tables 12 through 15 for both the SAM and SAMI sections.

The data in these tables were reviewed for reasonableness. The cracking data appear to be very reasonable. Few of either the SAM or SAMI sections have significant amounts of cracking. The roughness data is more variable than the cracking data. A brief review of the data shows that in 1982 many of the sections got smoother rather than rougher, 28 of 34 SAM sections got smoother and 38 of 53 SAMI sections got smoother. This could indicate a "drift" in the calibration of the roughness meter. Plots of roughness versus time are given in Appendix B.

TABLE 12 CRACKING DATA FOR SAM SECTIONS

ROUTE	DIR	MILEPOST BEG.	MILEPOST END	YEAR OF SAM	AGE @ SAM	PERCENT CRACKING 79	80	81	82	83	84	85
I10	E	316	316	74	14	0	0	2	3	3	4	10
I10	E	317	321	74	11	0	0	0	0	0	0	1
I10	W	323	331	74	11	0	0	0	0	0	0	0
I40	E	259	264	75	17	0	0	0	0	0	0	0
I40	E	265	268	74	12	0	0	0	0	0	0	0
I40	E	269	272	74	8	0	12	11	0	0	0	0
I40	E	278	283	75	9	0	25	23	0	0	0	0
I40	W	203	203	78	10	0	0	0	2	20	20	15
I40	W	269	283	74	12	0	12	5	0	0	0	0
S68	E	3	8	75	29	0	6	5	6	5	6	5
S68	E	16	27	75	29	0	6	6	6	7	7	9
S71	N	86	90	72	22	0	0	0	0	0	0	1
S87	N	177	177	67	16	0	2	2	2	0	0	0
S87	N	179	182	74	20	0	4	4	13	10	3	0
S87	N	186	193	74	19	0	2	3	4	3	3	2
S89L	N	549	549	81	2	0	0	0	0	0	0	0
S95	N	191	200	77	0	0	0	0	0	0	0	0
S264	E	323	344	76	16	0	6	8	10	11	12	12
S264	E	456	465	75	13	11	14	12	12	13	10	11
S264	E	466	471	75	13	4	8	6	4	4	1	2
U60	E	86	92	72	17	8	2	2	2	2	3	1
U60	E	93	98	73	18	2	2	2	1	1	2	2
U60	E	99	106	73	21	1	2	2	2	3	3	2
U60	E	107	107	73	20	0	0	0	0	0	0	0
U60	E	343	345	74	22	0	0	0	0	0	0	2
U60	E	349	352	74	32	24	20	0	0	0	0	0
U60	E	396	401	78	16	0	3	6	8	9	13	0
U70	E	255	256	74	27	9	38	8	0	0	0	0
U70	E	257	259	74	34	25	70	35	40	40	0	0
U89	S	66	67	72	48	0	14	14	14	14	17	6
U89	N	421	425	73	36		0	0	0	1	12	21
U89	N	426	430	73	36		0	0	0	1	0	0
U160	E	312	322	76	11	0	11	7	7	8	7	10
U160	E	323	331	76	16	0	11	8	10	10	9	0
U160	E	332	340	75	14	0	35	28	14	24	33	0
U160	E	345	357	75	14	0	36	17	10	14	22	0
U160	E	406	416	80	19	0	19	12	4	8	14	15
U163	N	396	416	77	19	0	6	7	8	7	8	8
U180	W	221	222	77	31	0	0	0	0	0	0	1
U180	W	236	250	76	17	0	2	2	2	3	2	3

TABLE 13 CRACKING DATA FOR SAMI SECTIONS

ROUTE	DIR	MILEPOST BEG.	END	YEAR OF SAMI	AGE @ SAMI	PERCENT CRACKING 79	80	81	82	83	84	85
I17	N	313	322	77	11	0	0	0	0	1	1	3
I40	E	319	330	75	13		0	0	0	0	0	0
I40	E	343	353	79	29		0	0	0	0	0	0
I40	E	354	359	75	13		0	0	1	1	1	0
I40	W	212	217	77	8		7	6	6	6	4	6
I40	W	343	347	79	13		0	0	0	0	0	0
I40	W	348	353	79	12		0	0	0	0	0	0
S64	E	283	285	82	0		27	27	30	0	1	0
S71	N	86	90	77	27	0	0	0	0	0	0	1
S73	N	341	348	77	28		0	0	0	0	0	0
S85	N	165	169	79	21	0	0	0	0	1	2	2
S85	N	170	170	79	21	0	0	0	0	0	0	0
S87	S	241	246	76	18		0	0	1	1	0	0
S87	N	248	257	77	21		2	3	6	7	5	7
S95	N	228	233	76	9	0	0	0	0	0	1	1
S169	N	11	14	79	0	0	1	4	0	0	0	0
S260	N	361	368	77	17		1	1	1	0	0	0
S264	E	441	447	79	17		0	0	0	0	1	0
S277	N	322	335	78	17		0	0	0	0	1	0
S277S	N	322	322	77	15			0	0	0	0	0
S504	E	466	469	76	15		0	0	0	1	1	1
U60	E	138	146	80	32	23	0	0	0	0	0	0
U60	E	189	190	82	29		53	23	0	0	0	0
U60	E	336	339	79	33	0	0	0	0	0	0	1
U66	E	56	61	78	10	0	0	0	0	1	1	2
U66	W	57	57	78	44	0	0	0	0	0	0	0
U66	W	58	61	78	44	0	0	0	0	2	2	3
U70	E	255	257	74	27	11	48	13	0	0	0	0
U70	E	258	259	74	34	30	68	45	43	43	0	0
U70	E	280	287	77	20	0	0	0	1	1	1	2
U70	E	301	306	77	18		0	1	1	1	2	2
U89	N	421	425	73	36		1	1	1	1	12	21
U89	N	426	430	73	36		0	1	1	1	0	0
U89	N	451	457	76	39		0	0	0	0	0	0
U89	N	467	470	80	18		5	0	0	0	0	0
U89	N	471	476	83	22		4	4	4	6	0	0
U89	N	477	477	83	23		10	8	0	9	0	0
U89	N	478	478	83	23		4	6	6	6	0	0
U89	N	479	481	76	16		0	0	0	0	0	0
U89	N	490	493	84	25		3	3	3	5	0	0
U89	N	508	511	77	19		0	0	0	0	0	0
U89	N	512	513	80	21		8	0	0	0	0	0
U89	N	518	523	80	41		0	0	0	0	0	0
U89A	N	319	331	80	46		0	0	0	0	0	0
U89	N	482	485	85	14							
U89	N	495	503	85	27							
U89A	N	318	318	80	52							

TABLE 13 CRACKING DATA FOR SAMI SECTIONS (Cont'd.)

ROUTE	DIR	MILEPOST BEG.END		YEAR OF SAMI	AGE @ SAMI	PERCENT CRACKING 79	80	81	82	83	84	85
U89A	N	345	348	76	40	1	1	1	1	1	0	0
U89A	N	349	349	76	40	0	0	0	0	0	0	0
U89A	N	351	352	78	12	0	0	1	0	0	0	0
U89A	N	357	370	77	39	0	0	0	0	0	0	0
U89A	N	609	610	82	42		15	22	0	0	0	0
U160	N	465	465	77	17		2	0	0	0	0	0
U160	N	466	470	77	16		0	0	0	0	0	0
U180	W	217	219	77	31		2	1	1	2	1	4
U180	W	223	235	76	18		0	0	0	0	0	0
U666	E	132	138	76	26		0	0	0	0	0	0
U666	E	316	316	76	30		0	0	0	0	0	0
U666	E	317	322	76	29	0	1	1	1	1	1	1
U666	E	357	368	78	29		0	0	0	0	0	0

TABLE 14 ROUGHNESS DATA FOR SAM SECTIONS

ROUTE	DIR	MILEPOST BEG.END	YEAR OF SAM	AGE @ SAM	ROUGHNESS (INCHES PER MILE) 72	73	74	75	76	77	78	79	80	81	82	83	84	85
I10	E	316 316	74	14	87	118	130	134	136	134	161	69	93	135	91	120	100	123
I10	E	317 321	74	11	87	145	136	148	150	164	179	58	84	87	77	104	77	103
I10	W	323 331	74	11	52	102	89	101	122	109	119	41	75	75	64	97	72	95
I40	E	259 264	75	17	26	53	59	96	145	173	177	130	56	82	85	96	98	137
I40	E	265 268	74	12	32	62	86	109	130	162	163	112	82	122	104	115	117	168
I40	E	269 272	74	8	100	141	152	159	170	199	211	232	238	235	93	109	108	151
I40	E	278 283	75	9	73	139	107	132	149	171	204	214	193	221	90	108	117	154
I40	W	203 203	78	10	74	111	97	129	137	192	104	93	115	128	127	125	98	180
I40	W	269 283	74	12	91	132	137	138	162	173	218	236	223	185	98	113	123	155
S68	E	3 8	75	29	159	188	185	187	201	183	201	243	250	227	222	305	343	351
S68	E	16 27	75	29	214	240	245	264	245	229	247	280	285	267	242	300	334	324
S71	N	86 90	72	22	206	191	234	231	200	83	133	113	119	129	103	135	143	147
S87	N	177 177	67	16		165	169	144	151	151	214	221	252	257	74	124	135	127
S87	N	179 182	74	20	192	206	209	57		65	90	105	100	113	124	145	134	141
S87	N	186 193	74	19	225	235	253	63	90	89	98	105	104	137	133	150	148	156
S89L	N	549 549	81	2			153	219	227		240		143	128	124	186	199	140
S95	N	191 200	77	0	327	306	425	461	375	176	223	73	85	115	79	105	108	116
S264	E	323 344	76	16	127	154	129	125	138	163	168	176	179	185	169	197	216	211
S264	E	456 465	75	13		277	261	263	238	286	275	310	285	286	246	329	334	278
S264	E	466 471	75	13		173	169	179	165	181	215	163	226	241	233	289	161	145
U60	E	87 92	72	17	121	174	168	202	211	160	141	143	142	164	143	178	168	164
U60	E	93 98	73	18	114	137	147	182	177	212	107	88	98	121	97	130	120	126
U60	E	99 106	73	21	98	131	180	205	189	224	106	80	90	99	82	115	96	101
U60	E	107 107	73	20	82	98	103	106	110	162	103	84	109	94	83	133	110	108
U60	E	343 345	74	22	183	194	256	260	290	350	173	48	61	66	82	109	88	125
U60	E	349 352	74	32	159	165	181	178	213	268	249	304	72	91	128	139	112	139
U60	E	396 401	78	16	147	167	156	155	184	201	204	216	221	186	227	228	216	100
U70	E	255 256	74	27	130	149	143	142	186	223	188	197	219	60	71	93	80	123
U70	E	257 259	74	34	141	160	162	158	203	223	220	229	245	204	238	88	107	118
U89	S	66 67	72	48				371	338	343			480	440	424	485	541	364
U89	N	421 425	73	36	155	210	161	183	171	150	161							
U160	E	312 322	76	11	160	156	168	168	191	192	211	218	233	248	242	267	252	233
U160	E	323 331	76	16	149	160	155	152	170	172	184	187	198	199	189	206	219	100
U160	E	332 340	75	14	186	206	195	171	200	200	216	212	216	215	194	210	223	100
U160	E	345 357	75	14	186	188	184	158	182	158	195	196	210	207	185	202	217	100
U160	E	406 416	80	19	168	179	172	170	194	209	212	219	246	218	221	250	290	267
U163	N	396 416	77	19	161	161	151	155	167	180	223	217	220	219	204	229	246	232
U180	W	221 222	77	31	197	207	216	236	201	118	128	111	118	126	104	139	128	158
U180	W	236 250	76	17	104	109	103	113	119	129	142	124	137	140	147	148	141	168

TABLE 15 ROUGHNESS DATA FOR SAMI SECTIONS

ROUTE	DIR	MILEPOST BEG.END	YEAR OF SAMI	AGE @ SAMI	ROUGHNESS (INCHES PER MILE) 72	73	74	75	76	77	78	79	80	81	82	83	84	85
I17	N	313 322	77	11	45	58	66	62	83	55	47	48	71	87	79	75	86	105
I40	E	319 330	75	13	183	211	247	43	51	106	64	62	81	98	86	126	115	160
I40	E	343 353	79	29	146	188	170	184	207	259	265	118	135	150	143	171	101	120
I40	E	354 359	75	13	171	207	194	85	60	114	75	74	98	103	95	127	110	100
I40	W	212 217	77	8	23	47	56	80	106	93	70	53	53	83	77	94	88	124
I40	W	343 347	79	13	156	214	205	219	243	288	292	140	189	181	162	203	126	128
I40	W	348 353	79	12	166	211	204	209	220	272	269	95	149	208	171	196	135	126
S64	E	283 285	82	0	217	240	258	279	276	285	282	321	342	381	86	110	97	114
S71	N	86 90	77	27	206	191	234	231	200	83	133	113	119	129	103	135	143	147
S73	N	341 348	77	28	158	169	184	166	178	121	111	88	97	99	82	103	97	127
S85	N	165 169	79	21	117	152	145	152	160	242	249	96	90	115	103	133	130	155
S85	N	170 170	79	21	132	161	166	174	172	249	227	96	120	133	125	148	131	140
S87	S	241 246	76	18	194	94	91	65	91	93	53	91	93	53	80	108	87	136
S87	N	248 257	77	21	161	174	159	150	157	168	180	115	135	147	158	177	178	216
S95	N	228 233	76	9	176	200	208	205	68	51	90	89	104	116	98	127	119	131
S169	N	11 14	79	0						55	97	145	160	215	75	90	73	86
S260	N	361 368	77	17	140	227	164	179	214	139	106	111	130	130	127	90	77	102
S264	E	441 447	79	17		241	260	228	232	248	258	165	153	169	157	174	179	145
S277	N	322 335	78	17	196	213	186	191	205	218	135	132	128	131	137	148	148	158
S277S	N	322 322	77	15									171	153	159	161	157	158
S504	E	466 469	76	15		139	152	129	171	94	95	85	129	117	98	130	154	94
U60	E	138 146	80	32	52	80	80	89	85	127	105	95	70	74	68	86	69	102
U60	E	189 190	82	29	74	79	52	60	81	74	116		101	114	73	81	102	107
U60	E	336 339	79	33		199	167	160	172	228	207	233	99	117	139	159	141	146
U66	E	56 61	78	10	44	48	64	65	68	78	70	66	77	86	69	86	85	121
U66	W	57 57	78	44	41	38	53	52	60	79	70		77	77	52	75	75	119
U66	W	58 61	78	44	40	42	63	66	67	76	67		79	83	69	92	88	114
U70	E	280 287	77	20	177	193	205	203	230	146	97	80	61	66	86	105	96	125
U70	E	301 306	77	18	113	113	119	105	130	141	113	106	103	96	113	138	127	143
U89	N	451 457	76	39	116	153	161	206	104	64	85	79	90	89	81	111	93	113
U89	N	467 470	80	18	156	198	204	262	283	212	192	230	65	88	87	105	110	129
U89	N	471 476	83	22	180	220	244	257	252	239	186	229	240	243	233	94	92	111
U89	N	477 477	83	23	126	156	207	236	224	241	239	246	255	220	248	74	93	146
U89	N	478 478	83	23	115	134	156	175	187	191	185	188	208	191	198	74	77	114
U89	N	479 481	76	16	176	200	276	270	113	132	125	153	158	181	180	159	123	121
U89	N	490 493	84	25	149	181	197	244	229	243	239	256	256	279	223	260	61	99
U89	N	508 511	77	19	123	148	144	175	176	91	113	116	106	107	108	124	123	136
U89	N	512 513	80	21	108	131	137	169	177	192	186	222	105	107	88	105	89	118
U89	N	518 523	80	41	72	80	77	101	99	101	111	152	74	94	76	98	102	109
U89A	N	319 331	80	46		161	175	187	169	192	218	111	163	138	126	144	137	150
U89	N	482 485	85	14														
U89	N	495 503	85	27														
U89A	N	318 318	80	52														

TABLE 15 ROUGHNESS DATA FOR SAMI SECTIONS (CONT.)

ROUTE	DIR	MILEPOST BEG.END	YEAR OF SAMI	AGE @ SAMI	ROUGHNESS (INCHES PER MILE) 72	73	74	75	76	77	78	79	80	81	82	83	84	85
U89A	N	345 348	76	40		248	232	242	102	110	125	116	127	118	141	139	138	147
U89A	N	349 349	76	40		200	209	217	164	160	95	74	89	99	89	100	94	110
U89A	N	351 352	78	12		181	218	250	129	119	70	53	77	82	80	87	69	102
U89A	N	357 370	77	39		201	206	237	201	92	111	101	124	110	106	123	123	131
U89A	N	609 610	82	42	139	163	154	189	187	188	188	204	201	139	73	112	116	124
U160	N	465 465	77	17		128	132	114	141	91	85	89	113	112	88	123	124	133
U160	N	466 470	77	16		148	147	146	159	104	107	92	127	123	109	128	141	148
U180	W	217 219	77	31	185	220	186	203	231	57	67	65	79	87	79	142	143	172
U180	W	223 235	76	18	296	295	340	398	95	89	113	116	128	136	142	141	128	160
U666	E	132 138	76	26	190	209	207	251	232	162	132	134	125	111	120	107	84	120
U666	E	316 316	76	30		111	131	142	122	154	148	139	151	171	174	193	164	176
U666	E	317 322	76	29		188	233	235	151	185	179	176	174	221	207	195	219	209
U666	E	357 368	78	29		187	203	198	236	287	287	133	138	155	148	162	185	165

Cracking of the SAM Sections

As shown in Table 12, there has been very little cracking of the SAM sections. Table 12 should be used in conjunction with Table 6 showing the age of the SAM when it was covered with either a sealcoat or an overlay. Note the first five interstate sections were overlaid in 1979 or earlier, so the data in Table 12 reflects the performance of the overlays. The other sections of interstate, except I40 W at MP 203, started to show cracking in 1980 and were overlaid in 1981. These sections have not developed new cracking in the four years since they were overlaid. The SAM on I40 W at MP 203 was placed in 1978. In 1981-1982 the cracking went from 2 to 20 percent and has remained essentially constant; the reduction in cracking in 1985 could be either patching or a variance in the data.

Four of the state routes with SAMs have developed some cracking. However, it appears the cracking develops in one year and then remains constant, as shown for sections:

S68 E MP 2 to 8

S68 E MP 16 to 27

S87 N MP 186 to 193

S264 E MP 323 to 344

S264 E MP 456 to 465

Thus, although some of the state highway sections with SAMs have some cracking, there does not appear to be a rapid progression of distress.

The first six US routes in Table 12 received either a friction course or overlay five to six years after the SAMs were placed. These treatments occurred from 1977 to 1980 so most of the data in Table 12 for these sections is for the behavior of the treated sections. The data base does not show the condition of the sections prior to the treatments, however, the very low percent cracking on these sections indicates good performance. It can be noted that U60 E at MP 349 to 352 had 20% cracking prior to a 2.5" overlay in 1980 and there is not reflective cracking shown in the section as of 1985.

All sections of route U160 show more cracking than any other SAM sections. The data for 1979 appears questionable since cracking goes from 0 to as much as 36% in 1980. The cracking in 1980 and 1984 appear to be at similar levels although there is a reduction in the amount of cracking in 1982. There is nothing in the construction history data file that would account for this reduction in the amount of cracking. Also, several sections went to zero cracking in 1985 without a suitable explanation in the construction data file.

Roughness of SAM Sections

The roughness data for the SAM sections are summarized in Table 14. These data were analyzed with the regression equation procedure of Lotus 123 (Ref. 21) to produce linear equations between roughness and the years after the SAM treatment as shown in Table 16, i.e.:

$$R = C_o + C_1 y \pm e$$

where:

R = Roughness

C_o, C_1 = regression coefficients

y = years after SAM Treatment

note $y = 1$ for the year of the treatment

e = standard error of the estimate.

TABLE 16 ROUGHNESS EQUATIONS FOR SAM SECTIONS

	C_o	C_1	S_e	R^2	n	dof	S_eCoef
1.	Insufficient data						
2.	124.80	10.20	4.12	0.95	5	3	1.30
3.	87.60	6.80	9.41	0.63	5	3	2.98
4.	80.06	27.10	15.92	0.88	4	2	7.12
5.	67.90	20.70	8.27	0.95	5	3	2.61
6.	130.86	15.89	6.09	0.97	7	5	1.15
7.	126.57	14.21	15.42	0.83	7	5	2.91
8.	91.71	8.00	24.85	0.37	7	5	4.7
9.	111.00	18.21	14.29	0.90	7	5	2.70
10.	149.55	16.18	29.00	0.79	11	9	2.77
11.	228.13	7.69	24.02	0.56	11	9	2.29
12.	208.00	2.40	26.32	0.02	4	2	11.77
13.	Insufficient data						
14.	50.00	9.00	9.07	0.89	9	7	1.17
15.	62.16	8.93	7.79	0.94	11	9	0.74
16.	90.50	27.50	19.15	0.84	4	2	8.56
17.	Insufficient data						
18.	141.60	7.02	10.26	0.83	10	8	1.13
19.	256.95	4.60	27.88	0.25	11	9	2.66
20.	145.64	12.92	24.02	0.71	9	7	3.10
21.	112.80	20.80	14.88	0.87	5	3	4.71
22.	117.00	18.00	10.49	0.91	5	3	3.32
23.	127.30	19.50	18.91	0.78	5	3	5.98
24.	75.30	13.50	17.53	0.66	5	3	5.54
25.	211.00	31.20	19.81	0.86	4	2	8.86
26.	240.56	-10.42	65.66	0.26	12	10	5.49
27.	204.57	2.36	15.17	0.12	7	5	2.87
28.	139.71	9.14	13.07	0.68	6	4	3.12

TABLE 16 ROUGHNESS EQUATIONS FOR SAM SECTIONS (CONT'D)

	C_o	C_1	S_e	R^2	n	dof	S_eCoef
29.	Insufficient data						
30.	189.87	7.06	14.49	0.71	10	8	1.60
31.	164.89	5.33	6.36	0.86	9	7	0.82
32.	188.73	3.08	12.63	0.38	10	8	1.39
33.	162.47	5.19	13.83	0.59	10	8	1.52
34.	213.67	10.00	22.41	0.47	6	4	5.36
35.	195.14	4.74	14.20	0.49	9	7	1.83
36.	108.72	3.37	13.92	0.33	9	7	1.80
37.	118.60	3.80	8.18	0.69	10	8	0.90

The Interstate sections have reasonable R^2 values except for I40 W MP 203, which has one low roughness measurement that cannot be explained by examining the construction data files. The equations all make sense in that there is a positive correlation between roughness and age. The average annual change in roughness is 12.5 inches per mile.

Six of the 9 equations for the state highway sections have good R^2 values. S71 N at MP 86 to 90 shows no correlation between the age of the SAM and roughness. The correlation for S 264 E at MP 456 to 465 is very poor. This section has high roughness, but there is no consistent trend in the data. The average annual change in roughness of the SAM sections is 10.7 inches per mile per year. Without the two sections which show a poor correlation, the annual change in roughness would be 12.7 inches per mile per year.

One of the US route sections has a negative C_1 coefficient which indicates the section is getting smoother. This section has a low R^2 which indicates a lot of scatter in the data points. The R^2 values for the US routes in general are lower than for the interstates or state routes. The average annual change in roughness for the US routes is 14.3 inches per mile.

Cracking of the SAMI Sections

As shown in Table 13, SAMI treatments have been extremely successful in preventing cracking. Only 3 of the 57 sections in the data base have developed a significant amount of cracking. Two of these sections are on U70 E at MP 255 to 257 and 258 to 259. The condition of this route before the SAMI was placed is unknown so there is no way to judge if the performance was acceptable or not. However, the route was 27 years old when the SAMI was placed and it lasted 8 years on one section and 9 years on the other section. The other section with cracking is U89 at MP 421 to 425. This section was 36 years old when the SAMI was placed and has 21% cracking after 12 years of service.

<u>Roughness of the SAMI Sections</u>

Linear regression analysis of roughness versus years after the SAMI treatment were developed as shown in Table 17. In general, the correlation between roughness and age is not as strong for the SAMI sections as it was for the SAM sections. One may rationalize this conclusion by assuming that the expected annual change on the SAMI sections should be less than for the SAM sections, and therefore a longer observation period is required to identify the trends in the data.

Reviewing the regression coefficients for the interstate sections shows three of the seven sections have R^2 better than 0.70. For these sections, the average annual change in roughness is 8.9 inches per mile. the section on I40 W at MP 348 to 353 would have a reasonable R^2 if one datum point was eliminated. The measurements from 1980 to 1981 changed by 59 inches per mile which is impossible for all practical purposes. This is the only section where the change in roughness per year was greater than the average for the interstate SAM sections.

There was more variance in the performance of the SAMI sections on state routes. Only three of ten sections have reasonable R^2 values. Two sections have negative coefficients for the annual change in roughness; these sections also have very low R^2 values indicating a lack of significant correlation. The average annual change in roughness for the sections with a R^2 greater than 0.7 is 7.0 inches per mile per year.

TABLE 17 ROUGHNESS EQUATIONS FOR SAMI SECTIONS

	C_o	C_1	S_e	R^2	n	dof	S_eCoef
1.	40.97	6.32	9.73	0.78	9	7	1.26
2.	36.67	8.92	20.22	0.70	11	9	1.93
3.	109.20	11.40	8.59	0.85	5	3	2.72
4.	73.75	3.48	16.8	0.34	11	9	1.60
5.	58.00	4.73	19.17	0.34	9	7	2.47
6.	145.30	9.90	21.83	0.41	5	3	6.90
7.	96.60	22.40	31.50	0.63	5	3	9.46
8.	84.00	7.10	10.88	0.52	4	2	4.87
9.	96.61	5.23	15.71	0.49	9	7	2.03
10.	103.03	-0.05	15.66	0.00	9	7	2.02
11.	78.14	9.82	10.36	0.83	7	5	1.96
12.	103.43	6.04	11.43	0.61	7	5	2.16
13.	129.67	-3.85	51.31	0.05	10	8	5.65
14.	136.03	5.55	26.88	0.27	9	7	3.47
15.	57.07	7.68	11.75	0.82	10	8	1.29
16.	Insufficient data						
17.	120.73	0.89	14.01	0.02	6	4	3.35
18.	Insufficient data						
19.	123.12	3.65	5.96	0.72	8	6	0.92
20.	Insufficient data						
21.	91.00	3.93	21.78	0.22	9	7	2.81
22.	61.87	4.66	11.42	0.42	6	4	2.73
23.	60.00	12.30	4.71	0.94	4	2	2.10
24.	100.80	9.34	14.39	0.65	6	4	3.44
25.	57.75	5.50	12.13	0.59	8	6	1.87
26.	43.50	6.49	20.20	0.31	6	4	4.83
27.	54.03	6.09	11.28	0.56	6	4	2.70
28.	215.59	-8.71	45.41	0.34	12	10	3.80
29.	151.31	10.78	17.34	0.77	9	7	2.20
30.	61.48	5.10	18.15	0.36	8	6	2.80
31.	109.67	-2.07	17.91	0.10	9	7	2.31
32.	161.65	1.03	14.70	0.07	12	10	1.23

TABLE 17 ROUGHNESS EQUATIONS FOR SAMI SECTIONS (Cont'd)

	C_o	C_1	S_e	R^2	n	dof	S_eCoef
33.	213.02	-5.87	35.70	0.28	12	10	2.98
34.	65.14	5.11	9.77	0.60	7	5	1.85
35.	56.93	11.54	5.69	0.95	6	4	1.36
36.	91.90	1.70	8.55	0.12	5	3	2.70
37.	32.33	36.00	13.88	0.93	3	1	9.81
38.	48.33	20.00	13.88	0.81	3	1	9.81
39.	135.07	1.72	25.88	0.04	10	8	2.85
40.	Insufficient data						
41.	94.78	3.80	8.29	0.64	9	7	1.07
42.	Insufficient data						
43.	70.07	6.31	8.82	0.69	6	4	2.11
44.	128.50	3.50	8.11	0.38	5	3	2.57
45.	101.73	4.47	6.42	0.83	10	8	0.71
46.	81.54	2.71	8.74	0.40	8	6	1.35
47.	59.71	3.95	11.47	0.45	8	6	1.77
48.	95.28	3.63	8.44	0.61	9	7	1.09
49.	67.00	15.70	12.58	0.80	4	2	5.62
50.	79.11	5.47	11.41	0.66	9	7	1.47
51.	92.22	5.43	10.95	0.69	9	7	1.41
52.	Insufficient data						
53.	88.67	6.57	9.80	0.82	10	8	1.08
54.	152.58	-6.18	13.92	0.63	9	7	1.80
55.	120.18	8.07	10.94	0.79	8	6	1.69
56.	158.93	5.94	14.41	0.64	10	8	1.59
57.	127.00	7.04	9.85	0.74	7	5	1.86

Eleven of the 34 SAMI sections on US routes had an R^2 greater than 0.7. Four sections had negative coefficients and on one of these sections, U666 E at MP 132 to 138, the R^2 was 0.63. Review of the data for this section in Table 12 shows the roughness does decrease 5 years and increases only 3 years. This is probably an extreme demonstration of the amount of variance in roughness measurements. The average annual change in roughness for the sections with R^2 of 0.70 or more is 12.2 inches per miles per year. This average includes a section where the change in roughness was 36 inches per mile per year, U89 N at MP 477. Without this section, the average change in roughness is 9.8 inches per mile per year for the SAMI sections on US routes.

DETAILED EVALUATION OF SELECT SECTIONS

The pavement management system construction history data base was searched for pairs of sections where the only difference in the construction history was the placement of a SAM or SAMI on one section and a conventional treatment on the other section. Three SAMI sections which met the criteria were located. The construction history of these sections and the corresponding control section are summarized in Table 18. The condition of each section was evaluated using the PAVER method and the pavement condition index was computed as shown in Table 19. Due to the extreme influence that rutting can have on the PCI, the condition index of the section was also computed without considering rutting as shown in Table 20.

Route U666, MP 322 and 324

This section allows a direct comparison between a SAMI with a 2.5 inch asphalt concrete surface layer to a conventional overlay with a 4.8

TABLE 18 CONSTRUCTION HISTORY OF SELECTED SECTIONS

	SAMI					CONTROL				
Route	MP	DATE	Lift	MTL*	TH	MP	DATE	Lift	MTL	TH
U666E	317-322	/47	1	BM	5.0	323-327	/48	1	BM	5.0
			2	BS	1.8			2	BS	1.8
		10/61	3	SC	0.3		10/61	3	SC	0.3
		9/68	4	SC	0.3		9/68	4	SC	0.3
		/76	5	RM	0.3		8/77	5	AC	4.8
			6	AC	2.5			6	FL	0.0
			7	FL	0.0			7	SC	0.3
U60E	336-339	/38	1	SM	6.0	326-335	/38	1	SM	6.0
			2	BS	2.0			2	BS	2.0
		8/69	3	SC	0.3		8/69	3	SC	0.3
		5/74	4	SC	0.3		5/74	4	SC	0.3
		10/79	5	RM	0.3		10/79	5	AC	1.5
			6	AC	1.5			6	FC	0.5
			7	FC	0.5					
U89N	482-485	/60	1	SM	18.0	486-489	/61	1	SM	9.0
			2	AB	6.0			2	AB	6.0
			3	AC	3.0			3	AC	3.0
			4	SC	0.3			4	SC	0.3
		10/70	5	FL	0.0		10/70	5	FL	0.0
		8/85	6	LC	2.0		6/84	6	AC	4.0
			7	RM	0.3			7	SC	0.3
			8	AC	1.5					
			9	SC	0.3					

*Material abbreviations are given in Table 9

TABLE 19 PCI FOR SELECT SECTIONS

Sample Unit*	Route U666		Route U60		Route U89	
	MP322	MP324	MP337	MP332	MP482	MP487
	SAMI	Control	SAMI	Control	SAMI	Control
1	90	57	86	82	100	100
2	56	69	89	68	100	100
3	48	54	84	77	100	100
4	71	51	85	73	100	100
5	48	55	81	72	100	99
6	44	51	84	69	100	100
7	55	53	78	68	100	100
8	62	80	81	60	100	100
9	66	83	72	68	100	100
10	51	56	62	72	100	100
11	42	44	80	74	100	100
12	71	51	82	68	100	100
13	62	54	79	68	100	100
14	51	62	76	57	100	100
15	57	62	74	61	99	100
$\bar{x}$	58.3	58.8	79.5	69.1	100	100
σ	12.6	10.9	6.7	6.5	0	0

*each sample unit is 100 feet long

TABLE 20 PCI FOR SELECT SECTIONS NOT CONSIDERING RUTTING

Sample Unit*	Route U666		Route U60		Route U89	
	MP322	MP324	MP337	MP332	MP482	MP487
	SAMI	Control	SAMI	Control	SAMI	Control
1	90	79	86	82	100	100
2	85	69	89	81	100	100
3	67	74	84	77	100	100
4	71	70	85	73	100	100
5	65	76	81	72	100	99
6	58	70	84	69	100	100
7	76	81	78	68	100	100
8	84	80	81	72	100	100
9	88	87	72	81	100	100
10	70	77	80	72	100	100
11	68	51	80	74	100	100
12	71	71	82	82	100	100
13	84	76	79	82	100	100
14	70	84	76	70	100	100
15	79	83	74	74	99	100
$\bar{x}$	75.1	75.2	80.7	75.3	100	100
σ	9.5	8.7	4.6	5.1	0	0

* each sample unit is 100 feet long.

inch asphalt concrete surface thickness. One of the design concepts for SAMI's is the stress absorbing characteristics of the asphalt-rubber allows the thinner surface layer placed with the SAMI to have performance equal to a thicker asphalt concrete overlay. As shown in Tables 19 and 20, the performance of the SAMI and control section are virtually identical.

Route U60, MP337 and MP332

This section allows comparison of the performance of a SAMI to a conventional overlay of equal thickness. As shown in Table 13, the only difference in the construction history of the SAMI and the control section, was the placement of an asphalt-rubber membrane when the pavement was overlaid in 1979. As shown in Tables 19 and 20, the overall condition of the control section is better than the performance of the SAMI section. This is a surprising finding. Table 20 reflects the extent of cracking on the sections. The condition index for the control section is about five points higher than the condition index of the SAMI section. The primary distress types on both sections was longitudinal and transverse cracking and a minor amount of alligator cracking. There was also some bleeding on the SAMI section.

Care must always be exercised when "after the fact" evaluations are made of pavement performance. In this case, one must wonder why the asphalt-rubber layer was placed on one pavement section and not on the adjacent section. Since these sections were not constructed as part of a research project, one may infer that the asphalt-rubber membrane was placed for an engineering reason. Perhaps the section of U60 from MP336 to 339 was more distressed than MP 326 to 335 and therefore the engineers elected to use a SAMI on one section and a conventional treatment on the other section. The pavement management data base does not have data on the condition of the pavements prior to 1979.

Route U89, MP482 and 487

This pavement was recently overlaid and therefore provides ATRC with the opportunity to study the complete performance history of a SAMI and conventional overlay. The condition survey demonstrated both sections are in excellent condition. The control section was dotted with small circles of asphalt. These may be early signs of bleeding, but they were too minor to be recorded as a distress at this time.

SUMMARY OF FIELD PERFORMANCE OF ASPHALT-RUBBER

The performance history of the highway sections constructed with asphalt-rubber certainly demonstrate the viability of the material as an alternative to conventional construction. The average life of SAMs placed on interstate highways was just over 5 years before overlay. Six of the eleven state highway sections with SAMs are still performing after 10 to 13 years. Other sections provided lives in the range of 3 to 16 years. SAMs were placed on 17 sections of US highways. US60 has seven of the sections and six of the US60 sections have received an additional treatment after 5 or 6 years.

SAMI sections were placed at one location on I17 and six locations on I40; two inches of the asphalt concrete on three of the I40 sections were removed and replaced with overlays in 1984, when the SAMIs were 5 years old. The failure of these has been attributed to the asphalt concrete overlay material rather than the asphalt-rubber membrane. The other SAMI sections on interstates are still in place. Ten of the 14

SAMIs placed on state routes are still in service after up to 9 years of service.

The most extensive use of asphalt-rubber is SAMIs placed on US routes; 37 sections were constructed from 1973 to 1984. Eight of the sections received a surface dressing within four years of the SAMI construction. Several of these sections received a fog seal at the time the SAMI was placed. One could speculate that the fog seal provided an excess of volatiles which could not penetrate the asphalt-rubber layer and therefore created a material problem at the pavement surface which required a surface dressing. In a study for the Federal Highway Administration, Shuler et al. (Ref. 22) put forth a hypothesis that when an asphalt-rubber membrane is placed between a new asphalt concrete level up course and a friction course, the friction course can become embedded in the membrane, creating excess binder at the surface. ADOT has not experienced this problem in the three layer system.

The traffic data for the asphalt-rubber sections were compiled and the cumulative axle loads on the pavement sections were computed both before and after the placement of the asphalt-rubber layers. These data were not useful in the analysis of pavement performance. In the future, historical traffic data should be maintained so mechanistic based performance models can be produced.

The performance data for the asphalt-rubber sections were very interesting. The SAM and SAMI sections show very little cracking after several years of service. Cracking data prior to the placement of the SAM or SAMI were only available for a few sections. However, the available data indicate the asphalt-rubber layers are effective in preventing reflection cracking. The roughness data for the SAM sections where reliable equations could be established showed an annual change in roughness of 12.5, 12.7, and 14.3 inches per mile for interstate, state, and US routes. The corresponding data for SAMI sections was 8.9, 7.0, and 12.2. The actual performance of the asphalt-rubber sections is probably better than these values indicate since these numbers were derived from a subset of the data where there was a positive correlation between age and roughness. The balance of the sections, the rate of change of roughness was too small to be detected within the measurement error of the Maysmeter.

The comparison of SAMI sections with "control" sections selected from the pavement management system data base did not show any significant difference in the performance of the sections. The maximum difference in the pavement condition index between the control and SAMI sections was 5.4.

CHAPTER IV PERFORMANCE OF CONVENTIONAL PAVEMENT TREATMENTS

The ability of asphalt-rubber to provide a durable pavement surface was demonstrated in the previous chapter. However, comparisons of asphalt-rubber with conventional treatments failed to provide superior performance of the asphalt-rubber. In this chapter, the performance of conventional seal coats and asphalt-concrete overlays is analyzed using the data in the ADOT pavement management system data base.

The pavement management data base was queried to generate six files for the performance of seal coats and overlays on interstate, U.S. highway, and state routes. These files were limited to projects performed between 1979 to 1982, except for seal coats on interstates. The PMS data base only contains two sections where seal coats were placed on interstates. The characteristics of the sections are given in Tables 21 to 26.

PERFORMANCE OF SEAL COATS

The performance of the sections with respect to roughness and cracking which received seal coats are given in Tables 27 to 32. The two interstate sections are both on I8 MP 154, one section in each direction. The roughness of these sections was very low in 1972 and there has been a consistent increase over the 14 year observation period. Regression analysis of these data shows the roughness increasing at a rate of 7.9 inches per mile per year.

Both the interstate sections have developed cracking. Between 1983 and 1984, the east bound section shows a considerable reduction in the level of cracking, which is unexplained by information in the data base.

TABLE 21 CHARACTERISTICS OF INTERSTATE SECTIONS WITH SEAL COATS

ROUTE			MILEPOST BEG	END	ADT	ADL	GF	MAINT COST	PROJECT		YEAR	LIFT	THICK NESS
ART	NO	D	BMP	EMP	ADT	ADL	GF	MAINT		PROJECT	YR	L1	T1
I	8	E	152	154	5211	835	2.4	1295	I	8- 2-905	69	SC	0.3
I	8	W	152	154	5211	835	2.4	1182	I	8- 2-905	69	SC	0.3

TABLE 22 CHARACTERISTICS OF INTERSTATE SECTIONS WITH OVERLAY

ROUTE	MILEPOST BEG	END	ADT	ADL	GF	MAINT COST	PROJECT	YEAR	LIFT 1	THICKNESS	LIFT 2	THICKNESS
I 8 E	136	136	6770	1164	4.1	0	IR 8- 2- 79	81	AC	4.0	FC	0.5
I 8 W	136	136	6770	1164	4.1	0	IR 8- 2- 79	81	AC	2.0	FC	0.5
I 10 E	14	15	16447	2092	5.0	2614	FI 10- 1- 54	79	AC	1.3	FC	0.5
I 10 E	277	281	16977	1669	1.4	717	I 10- 5- 40	79	AC	3.0	FC	0.5
I 10 E	302	303	14384	1478	1.7	1831	IR 10- 5- 52	79	AC	2.0	FC	0.5
I 10 E	321	321	11049	1382	1.8	439	I 10- 6- 77	79	AC	2.0	FC	0.5
I 10 W	14	15	16447	2092	5.0	742	FI 10- 1- 54	79	AC	1.3	FC	0.5
I 10 W	302	303	14384	1478	1.7	740	IR 10- 5- 52	79	AC	2.0	FC	0.5
I 10 W	329	331	11744	1472	2.3	1516	I 10- 6- 77	79	AC	2.0	FC	0.5
I 17 N	263	269	15470	1099	5.4	394	IRI 17- 2- 68	80	AC	3.0	FC	0.5
I 17 S	225	230	20382	673	3.8	2140	I 17- 1-136	81	AC	3.3	FC	0.5
I 17 S	264	269	15469	1098	5.4	333	IRI 17- 2- 68	80	AC	4.5	FC	0.5
I 19 N	23	24	6904	254	3.1	471	I 19- 1- 29	79	AC	6.0	FC	0.5
I 40 E	49	49	6954	205	4.4	266	I 40- 1- 33	80	AC	8.0	FC	0.5
I 40 E	53	53	13578	406	7.4	408	I 40- 1- 33	80	AC	4.3	FC	0.5
I 40 E	145	146	7366	870	3.9	276	I 40- 2- 38	79	AC	9.5	FC	0.5
I 40 E	259	268	12027	1466	4.2	2831	IRI 40- 4-103	79	AC	6.0	FC	0.5
I 40 E	269	283	11880	1446	4.0	1894	FII 40- 4- 79	81	AC	5.0	FC	0.5
I 40 W	49	49	6954	205	4.4	58	I 40- 1- 33	80	AC	8.0	FC	0.5
I 40 W	53	53	13578	406	7.4	74	I 40- 1- 33	80	AC	4.3	FC	0.5
I 40 W	145	146	7366	870	3.9	634	I 40- 2- 38	79	AC	9.5	FC	0.5
I 40 W	251	251	10956	1099	4.1	34	I 40- 4- 62	79	AC	9.5	FC	0.5
I 40 W	269	283	11880	1446	4.0	3680	FII 40- 4- 79	81	AC	5.0	FC	0.5

TABLE 23 CHARACTERISTICS OF STATE HIGHWAY SECTIONS WITH SEAL COATS

ROUTE	MILEPOST BEG	END	ADT	ADL	GF	MAINT COST	PROJECT		YEAR	LIFT	THICKNESS
S 61	N353	356	2435	135	5.3	142	F074-	1-902	81	SC	0.3
S 67	S580	584	1062	16	2.6	1758	S212-	-905	81	SC	0.3
S 67	S585	610	1062	16	2.6	698	S212-	-905	81	SC	0.3
S 72	E 14	17	1179	46	2.9	1246	S265-	-911	80	SC	0.3
S 72	E 19	27	1179	46	2.9	275	S265-	-911	80	SC	0.3
S 72	E 36	49	879	34	0.6	222	S265-	-912	80	SC	0.3
S 77	N396	401	889	25	1.9	478	S245-	-902	80	SC	0.3
S 77	N402	408	889	25	1.9	1007	S245-	-902	80	SC	0.3
S 85	S 33	36	706	15	0.7	733	F075-	1-901	81	SC	0.3
S 85	S 37	41	4305	90	2.1	538	F075-	1-901	81	SC	0.3
S 92	E326	335	3928	83	3.2	710	S577-	-906	81	SC	0.3
S 95	N149	151	5950	198	2.7	778	F063-	2-906	82	SC	0.3
S 99	N 62	71	351	23	-0.2	2632	S489-	-905	79	SC	0.3
S188	W259	267	731	16	4.5	3703	S456-	-905	81	SC	0.3
S188	W270	272	768	17	4.9	5679	S456-	-905	81	SC	0.3
S277	N306	321	1412	125	2.3	1398	S428-	-910	80	SC	0.3
S389	N 17	20	886	30	2.2	531	S213-	-902	81	SC	0.3
S389	N 21	29	886	30	2.2	2296	S213-	-902	81	SC	0.3
S389	N 30	32	886	30	2.2	2552	S213-	-902	81	SC	0.3
S473	S 1	9	177	5	4.8	3633	S982-	-901	81	SC	0.3

TABLE 24 CHARACTERISTICS OF THE STATE HIGHWAY ROUTES WITH OVERLAY

ROUTE	MILEPOST BEG	END	ADT	ADL	GF	MAINT COST	PROJECT	YEAR	LIFT 1	THICKNESS	LIFT 2	THICKNESS
S 8B	E 1	3	17875	575	0.9	59	M950- 2-502	79	AC	6.0	FC	0.5
S 40B	E274	275	627	4	27.2	52	I-40- 4- 49	80	AC	1.5	FC	0.5
S 61	N372	381	1918	105	3.1	1120	F074- 1-501	81	AC	2.0	SC	0.3
S 64	E271	276	2564	14	4.1	550	F033- 1-505	79	AC	3.0		0.0
S 71	N103	109	756	12	3.2	430	F070- 1-502	79	AC	1.5	SC	0.3
S 77	N361	363	4897	267	1.4	116	F027- 1-507	80	AC	2.0	SC	0.3
S 82	E 15	18	731	18	4.7	99	S275- -503	81	AC	2.0	SC	0.3
S 85	N189	189	34534	2105	3.7	14975	M504- 3-503	79	AC	3.0	FC	0.5
S 85	N190	190	34534	2105	3.7	16785	M504- 3-503	79	AC	2.5	FC	0.5
S 86	E167	169	20167	397	5.2	1647	F056- 1- 1	79	AC	7.0	FC	0.5
S 87	N135	145	3115	33	1.5	957	F021- 1-503	79	AC	2.0	FC	0.5
S 87	N231	240	4870	107	3.4	2904	F053- 1-509	79	AC	1.5	FC	0.5
S 87	N241	246	6781	149	4.2	1454	F053- 1-930	79	AC	1.5	FC	0.5
S 87	S172	172	35920	385	5.0	49	F028- 1- 6	79	AC	11.0	FC	0.5
S 88	E199	199	6527	145	7.3	3050	S214- -508	79	AC	5.5	FL	0.0
S 90	E322	324	6734	145	6.5	366	F013- 1-503	79	AC	1.5	FC	0.5
S260	E378	385	1515	41	4.3	65	F044- 1-506	79	AC	1.3	SC	0.3
S260	W340	340	4383	212	4.4	194	F026- 1-510	79	AC	9.0	FC	0.5
S277	N336	336	2559	265	3.0	491	S428- -502	79	AC	8.5	SC	0.3
S279	N288	299	3984	131	3.5	149	*RS326- - 6	80	AC	3.0	FC	0.5
S287	N120	121	3099	167	3.2	0	RS251- - 4	79	AC	6.5	FC	0.5
S287	N122	122	3099	167	3.2	89	RS251- - 4	79	AC	7.0	FC	0.5
S377	N 1	6	790	38	3.5	90	F069- 1-503	81	AC	3.0	SC	0.3
S377	N 7	13	790	38	3.5	212	F069- 1-502	80	AC	1.5	SC	0.3
S377	N 14	33	790	38	3.5	61	F069- 1-501	80	AC	3.0	SC	0.3

TABLE 25 CHARACTERISTICS OF US HIGHWAY SECTIONS WITH SEAL COATS

ROUTE	MILEPOST		ADT	ADL	GF	MAINT	PROJECT	YEAR	LIFT	THICK
	BEG	END				COST				NESS
U 70 E	307	313	2300	83	1.5	111	F022- 4-933	79	SC	0.3
U 80 E	353	356	4078	210	2.7	253	F016- 1-912	80	SC	0.3
U 89 N	296	298	1414	23	4.9	21	F025- 1-917	81	SC	0.3
U 89 N	299	302	1414	23	4.9	22	F025- 1-917	81	SC	0.3
U 89 N	440	442	8007	376	3.9	791	F037- 1-916	79	SC	0.3
U 89 N	443	449	8007	376	3.9	963	F037- 1-916	79	SC	0.3
U 89AN	569	571	1470	45	4.0	696	F037- 3-913	80	SC	0.3
U 95 N	75	78	1257	50	6.6	48	F063- 1-904	79	SC	0.3
U 95 N	79	87	1257	50	6.6	62	F063- 1-904	79	SC	0.3
U 95 N	88	103	1490	59	7.0	142	F063- 1-904	79	SC	0.3
U180 E	348	353	496	27	1.1	2174	F051- 1-912	81	SC	0.3
U180 E	424	426	1408	29	2.5	929	F051- 2-908	79	SC	0.3
U180 E	427	429	783	16	0.6	1616	F051- 2-908	79	SC	0.3
U666 E	88	92	1369	69	2.4	607	F057- 1-902	79	SC	0.3
U666 E	93	98	1524	77	2.5	660	F057- 1-903	80	SC	0.3
U666 E	109	111	1841	92	1.6	549	F057- 1-904	80	SC	0.3
U666 E	345	352	537	30	4.5	0	F071- 1-901	79	SC	0.3
U666 E	353	356	537	30	4.5	500	F071- 1-901	79	SC	0.3
U666 E	357	367	537	30	4.5	0	F071- 1-901	79	SC	0.3

TABLE 26 CHARACTERISTICS OF U.S. HIGHWAY ROUTES WITH OVERLAY

ROUTE	MILEPOST BEG	END	ADT	ADL	GF	MAINT COST	PROJECT	YEAR	LIFT 1	THICKNESS	LIFT 2	THICKNESS
U 60 E	152	152	21347	558	1.1	2272	F022- 2- 15	81	AC	10.0	FC	0.5
U 60 E	276	286	3266	149	6.1	240	F026- 1-514	81	AC	2.0	SC	0.3
U 60 E	310	315	3415	156	6.7	1862	F026- 1-515	81	AC	1.5	SC	0.3
U 60 E	316	331	2312	103	1.5	1681	F026- 1-513	79	AC	1.5	FC	0.5
U 60 E	332	335	2036	90	0.2	228	DP-F026- 1- 17	79	AC	1.5	FC	0.5
U 60 E	340	341	17306	786	4.8	3144	F026- 1-510	79	AC	9.0	FC	0.5
U 60 W	152	152	21347	558	1.1	2052	F022- 2- 15	81	AC	10.0	FC	0.5
U 70 E	288	292	2364	86	1.8	707	F022- 4-514	79	AC	3.0	FC	0.5
U 70 E	339	340	9790	352	-0.1	1355	F022- 4-935	79	AC	1.0		0.0
U 89 N	70	70	39243	1223	3.2	60	F031- 1- 12	79	AC	8.0	FC	0.5
U 89 N	75	79	28364	885	3.3	2218	F031- 1- 11	79	AC	6.0	FC	0.5
U 89 N	93	111	1777	56	4.7	547	F081- 1-501	79	AC	1.5	FC	0.5
U 89 N	346	353	1203	66	3.3	2206	F025- 2-507	79	AC	1.5	FC	0.8
U 89 N	525	525	2575	120	4.7	1752	F041- 1-503	80	AC	1.5	SC	0.3
U 89 N	526	526	2575	120	4.7	2182	F041- 1-503	80	AC	3.0	SC	0.3
U 89 N	525	531	2575	120	4.7	1752	F041- 1-503	80	AC	1.5	SC	0.3
U 89 S	70	70	39243	1223	3.2	0	F031- 1- 12	79	AC	8.0	FC	0.5
U 89 S	75	79	28364	885	3.3	0	F031- 1- 11	79	AC	6.0	FC	0.5
U 89AN	580	593	1359	46	0.4	3287	F037- 3-503	80	AC	1.5	SC	0.3
U 89AN	594	599	1359	46	0.4	167	F037- 3-506	80	AC	3.0		0.0
U 89AN	600	613	2197	76	1.5	209	F037- 3-504	80	AC	3.0		0.0
U 93 S	100	111	3159	81	2.8	697	F035- 1-507	80	AC	2.0	FC	0.5
U160 E	373	382	3303	117	1.6	1516	F064- 1-501	79	AC	1.5	FC	0.5
U163 N	395	395	9806	171	5.8	1206	F083- 1-501	81	AC	1.5	FC	0.5
U191 N	44	51	1232	57	2.8	713	F077- 1-501	79	AC	1.5	FC	0.5
U191 N	104	108	795	37	3.1	2325	F077- 1-503	79	AC	2.0	SC	0.3
U666 E	30	38	1277	66	2.4	37	S206- -506	79	AC	3.0	SC	0.3
U666 E	196	204	324	16	4.3	71	F051- 2-507	80	AC	1.5	SC	0.3
U666 E	205	220	141	7	5.6	6	F051- 2-506	79	AC	1.5	SC	0.3
U666 W	157	158	2501	124	-0.1	185	F051- 2- 3	80	AC	9.0	FC	0.5
U666 W	159	159	2501	124	-0.1	225	F051- 2- 3	80	AC	7.0	FC	0.5
U666 W	160	160	2501	124	-0.1	2764	F051- 2- 3	80	AC	8.5	FC	0.5

TABLE 27 ROUGHNESS OF INTERSTATE SECTIONS WITH SEAL COATS

ROUTE		MILEPOST		ROUGHNESS														
		BEG	END	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
I 8	E	152	154	15	26	29	38	30	20	67	40	76	82	77	104	118	139	125
I 8	W	152	154	15	24	34	32	26	18	47	42	58	40	57	78	98	95	144

TABLE 28 CRACKING OF INTERSTATE SECTIONS WITH SEAL COATS

ROUTE		MILEPOST		CRACKING							
		BEG	END	79	80	81	82	83	84	85	86
I 8	E	152	154	0	4	4	9	14	6	6	12
I 8	W	152	154	0	0	1	1	3	1	2	7

TABLE 29 ROUGHNESS OF STATE HIGHWAY SECTIONS WITH SEAL COATS

ROUTE		MILEPOST		ROUGHNESS														
		BEG	END	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
S 61	N	353	356	0	189	242	223	307	125	110	102	123	139	172	178	172	174	180
S 67	S	580	584	206	231	199	222	219	233	240	255	253	245	285	263	260	253	279
S 67	S	585	610	172	182	164	180	205	203	217	237	229	219	249	237	236	215	251
S 72	E	14	17	85	68	92	87	91	83	124	112	134	136	125	154	157	161	164
S 72	E	19	27	92	105	101	102	98	92	130	112	136	134	102	144	149	149	158
S 72	E	36	49	183	161	191	212	180	185	211	184	180	169	140	190	201	190	196
S 77	N	396	401	116	135	178	142	159	192	164	182	196	201	194	197	218	190	219
S 77	N	402	408	173	205	219	205	226	288	265	301	318	308	306	304	[illegible]	310	356
S 85	S	33	36	66	68	74	83	89	102	108	101	90	65	79	[illegible]	75	104	106
S 85	S	37	41	53	80	83	88	90	104	121	109	[illegible]	67	89	103	89	111	118
S 92	E	326	335	52	46	41	57	73	[illegible]	54	58	59	88	84	93	86	109	108
S 95	N	149	151	127	149	157	[illegible]	186	190	211	223	219	134	129	152	155	156	152
S 99	N	62	[illegible]	0	268	279	258	281	270	314	321	346	313	321	323	341	322	339
S188	W	[illegible]	267	0	273	292	271	258	306	274	285	342	315	344	332	363	328	328
S188	W	270	272	0	235	235	220	217	265	249	242	271	246	256	277	287	226	231
S277	N	306	321	199	212	186	193	208	224	189	217	219	201	207	212	222	226	204
S389	N	17	20	111	120	115	148	142	147	162	166	166	161	179	189	195	173	199
S389	N	21	29	85	92	91	114	118	120	130	141	165	143	167	174	182	176	203
S389	N	30	32	93	117	107	113	127	125	139	156	177	134	174	172	193	172	196
S473	S	1	9	0	0	281	257	277	311	310	343	352	323	331	330	338	327	375

TABLE 30 CRACKING OF STATE HIGHWAY SECTIONS WITH SEAL COATS

ROUTE		MILEPOST		CRACKING							
		BEG	END	79	80	81	82	83	84	85	86
S 61	N	353	356	0	0	0	0	0	0	0	0
S 67	S	580	584	0	0	0	1	1	2	3	5
S 67	S	585	610	0	0	3	3	2	3	4	6
S 72	E	14	17	0	0	4	5	8	11	12	16
S 72	E	19	27	0	0	2	4	5	4	5	8
S 72	E	36	49	0	0	1	3	4	6	7	8
S 77	N	396	401	0	4	2	2	2	2	4	4
S 77	N	402	408	0	14	6	6	6	11	20	23
S 85	S	33	36	8	10	12	5	8	6	4	6
S 85	S	37	41	6	5	9	2	3	2	2	4
S 92	E	326	335	0	2	2	2	2	1	2	3
S 95	N	149	151	0	26	16	0	1	5	4	5
S 99	N	62	71	0	0	0	0	1	2	6	8
S188	W	259	267	2	5	6	0	0	1	2	2
S188	W	270	272	0	0	0	0	0	0	0	1
S277	N	306	321	0	0	5	8	17	15	30	31
S389	N	17	20	0	3	3	4	4	3	3	3
S389	N	21	29	0	2	3	7	7	7	6	5
S389	N	30	32	0	6	3	8	5	7	12	2
S473	S	1	9	0	10	8	3	7	7	16	21

TABLE 31 ROUGHNESS OF US HIGHWAY SECTIONS WITH SEAL COATS

ROUTE	MILEPOST		ROUGHNESS														
	BEG	END	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
U 70 E	307	313	128	135	130	125	147	171	94	88	88	83	95	119	106	133	122
U 80 E	353	356	112	118	127	130	159	150	60	57	60	93	66	99	68	113	90
U 89 N	296	298	311	346	268	313	275	133	143	166	152	187	171	181	173	193	193
U 89 N	299	302	300	362	237	271	250	158	158	182	167	203	183	200	182	196	206
U 89 N	440	442	144	173	210	60	71	59	79	80	104	100	81	119	104	135	167
U 89 N	443	449	121	173	157	110	118	109	118	111	108	90	80	121	103	135	150
U 89AN	569	571	248	277	192	218	215	208	221	94	115	95	100	122	115	125	164
U 95 N	75	78	60	74	55	66	60	56	106	108	116	130	103	157	156	193	200
U 95 N	79	87	73	76	79	88	90	80	134	153	139	178	145	192	191	200	209
U 95 N	88	103	238	243	267	271	244	206	254	277	241	267	230	269	273	264	259
U180 E	348	353	0	55	61	67	93	140	98	107	127	151	126	151	151	152	123
U180 E	424	426	0	0	85	77	100	136	117	122	101	99	118	141	126	148	142
U180 E	427	429	0	94	95	90	108	148	130	127	120	110	121	151	138	163	158
U666 E	88	92	159	172	155	185	222	174	151	119	149	160	159	172	171	173	167
U666 E	93	98	201	208	193	212	193	239	222	143	148	139	166	178	176	167	166
U666 E	109	111	153	162	151	156	180	129	137	125	135	115	140	154	152	135	142
U666 E	345	352	0	224	258	246	262	321	293	143	150	162	159	157	171	161	145
U666 E	353	356	0	213	231	241	280	330	350	160	170	180	176	176	194	184	176
U666 E	357	367	0	181	194	194	231	285	281	128	129	150	141	152	158	154	146

TABLE 32 CRACKING OF US HIGHWAY SECTIONS WITH SEAL COATS

ROUTE	MILEPOST		CRACKING							
	BEG	END	79	80	81	82	83	84	85	86
U 70 E	307	313	0	1	1	1	1	1	1	2
U 80 E	353	356	0	0	0	0	0	0	0	0
U 89 N	296	298	0	0	0	0	0	1	0	0
U 89 N	299	302	0	0	0	0	0	0	0	0
U 89 N	440	442	0	2	3	3	4	4	6	5
U 89 N	443	449	0	0	1	1	1	2	4	6
U 89AN	569	571	0	0	0	2	2	2	2	8
U 95 N	75	78	0	7	6	6	9	9	10	11
U 95 N	79	87	0	6	6	7	15	16	17	18
U 95 N	88	103	0	1	2	5	13	14	15	19
U180 E	348	353	0	2	1	0	0	0	1	0
U180 E	424	426	0	0	0	0	0	0	1	2
U180 E	427	429	0	1	1	1	1	2	3	3
U666 E	88	92	0	0	0	1	1	1	1	2
U666 E	93	98	0	0	0	1	1	2	2	4
U666 E	109	111	0	0	0	0	0	0	0	1
U666 E	345	352	0	0	0	0	0	0	0	0
U666 E	353	356	0	0	0	0	0	0	0	0
U666 E	357	367	0	0	0	0	0	0	0	0

The west bound section had a low level of cracking from 1981 to 1985, but the 1986 data shows a significant increase in cracking.

State Highway Sections with Seal Coats

The cracking and roughness data for the state highway sections with seal coats are given in Tables 29 and 30. Review of the roughness data shows there is generally little if any reduction in roughness in the year following the seal coat as should be expected. Regression equations of roughness versus time after the overlay are given in Table 33. Only four of these equations have an R^2 greater than 0.70 and the regression coefficient for these sections in the range of 6.1 to 9.6 which represents the change in roughness per year. The range of the change in roughness for all sections was 1.1 to 9.6. One section had a negative coefficient, but this result is not meaningful as indicated by the very low R^2. Over all the rate of change in roughness of the seal coat on state highway sections is slightly lower than the change in roughness on the SAM sections on state routes.

Table 30 shows several state highway sections have developed significant amounts of cracking. Only one section is without cracks. The majority of the sections have less than 10% cracking. Three sections have more than 20 percent cracking. The seal coat does not appear to be effective in preventing cracks. Several sections with cracking prior to the seal coat, developed reflection cracking within one or two years after the seal coat was placed. The SAM data indicates superior performance with respect to cracking.

TABLE 33 ROUGHNESS EQUATIONS FOR STATE HIGHWAY SECTIONS WITH SEAL COATS

ROUTE			MILEPOST BEG	MILEPOST END	Co	C1	Se Y	R2	n	DOF	Se Coe
S	61	N	353	356	148.67	5.86	11.67	0.52	6	4	2.79
S	67	S	580	584	257.07	2.03	16.53	0.06	6	4	3.95
S	67	S	585	610	228.80	1.63	16.32	0.04	6	4	3.90
S	72	E	14	17	122.71	6.14	8.38	0.75	7	5	1.58
S	72	E	19	27	118.43	5.11	15.87	0.37	7	5	3.00
S	72	E	36	49	159.29	5.39	18.97	0.31	7	5	3.58
S	77	N	396	401	192.00	2.54	11.27	0.22	7	5	2.13
S	77	N	402	408	298.57	5.29	17.14	0.35	7	5	3.24
S	85	S	33	36	61.07	7.46	10.22	0.70	6	4	2.44
S	85	S	37	41	65.47	8.77	9.36	0.79	6	4	2.24
S	92	E	326	335	77.87	4.80	7.35	0.65	6	4	1.76
S	95	N	149	151	133.80	5.00	9.18	0.50	5	3	2.90
S	99	N	62	71	323.32	1.10	12.56	0.05	8	6	1.94
S	188	W	259	267	330.20	1.37	18.30	0.02	6	4	4.37
S	188	W	270	272	269.33	-4.43	25.77	0.11	6	4	6.16
S	277	N	306	321	210.14	0.71	10.33	0.03	7	5	1.95
S	389	N	17	20	164.87	5.09	12.07	0.44	6	4	2.89
S	389	N	21	29	140.67	9.57	8.88	0.84	6	4	2.12
S	389	N	30	32	141.00	9.29	15.35	0.62	6	4	3.67
S	473	S	1	9	311.73	7.31	14.91	0.51	6	4	3.56

U.S. Highway Sections with Seal Coats

The roughness and cracking data for the U.S. Highway sections with seal coats are given in Tables 31 and 32. As shown in Table 31, there is not a noticeable and consistent trend for the placement of a seal coat to reduce roughness. Regression equations for the change in roughness with time are given in Table 34. Only three sections have an R^2 greater than 0.7. The roughness on these sections changes at a rate of 6 to 13 inches per mile per year. The rate of change in roughness for the US Highway routes with seal coats is considerably less than for the SAM sections on U.S. Highway. Several of the SAM sections on U.S. Routes had changes in roughness in excess of 15 inches per mile per year.

As shown in Table 32, three of the U.S. Highway routes with seal coats have developed more than 10% cracking. Seven of the 18 sections have not developed any cracking. Overall, the performance of the seal coats on U.S. Highway sections is comparable to the performance of the SAM sections with respect to cracking. This conclusion does not consider the initial condition of the pavement since the data were not available.

PERFORMANCE OF OVERLAYS

The cracking data, roughness data and roughness regression equations are presented in Tables 35 through 43 for the thru highway types. The characteristics of the projects with overlays are given in Tables 22, 24, and 26. The thicknesses of the overlays range from 1.3 to 9.5 inches on the Interstates, 1.5 to 11 inches on the State Highways and 1.5 to 10 inches on the U.S. Highways. In all but 3 cases a surface layer of either a friction course or seal coat was placed at the time of

TABLE 34 REGRESSION EQUATIONS FOR US HIGHWAY SECTIONS WITH SEAL COATS

ROUTE	MILEPOST BEG	MILEPOST END	Co	C1	Se Const	R2	n	DOF	Se Coe
U 70 E	307	313	74.46	6.62	9.89	0.76	8	6	1.53
U 80 E	353	356	65.29	4.71	18.53	0.27	7	5	3.50
U 89 N	296	298	174.20	2.51	9.40	0.24	6	4	2.25
U 89 N	299	302	191.40	1.03	11.24	0.04	6	4	2.69
U 89 N	440	442	67.64	9.69	17.85	0.67	8	6	2.75
U 89 N	443	449	86.11	5.81	19.33	0.39	8	6	2.98
U 89AN	569	571	87.71	7.93	15.98	0.58	7	5	3.02
U 95 N	75	78	83.18	13.82	17.17	0.82	8	6	2.65
U 95 N	79	87	133.93	9.32	15.05	0.73	8	6	2.32
U 95 N	88	103	257.54	0.55	17.58	0.01	8	6	2.71
U180 E	348	353	148.53	-1.77	15.04	0.06	6	4	3.59
U180 E	424	426	98.96	5.70	13.03	0.57	8	6	2.01
U180 E	427	429	106.75	6.50	12.28	0.66	8	6	1.90
U666 E	88	92	131.86	5.98	11.35	0.66	8	6	1.75
U666 E	93	98	145.71	4.29	11.95	0.42	7	5	2.26
U666 E	109	111	128.57	2.61	12.82	0.19	7	5	2.42
U666 E	345	352	150.96	1.12	9.74	0.08	8	6	1.50
U666 E	353	356	165.00	2.67	8.06	0.43	8	6	1.24
U666 E	357	367	129.43	3.40	8.15	0.55	8	6	1.26

TABLE 35 CRACKING OF INTERSTATE SECTIONS WITH OVERLAY

ROUTE	MILEPOST BEG	MILEPOST END	CRACKING 79	80	81	82	83	84	85	86
I 8	E136	136	20	15	15	0	0	0	0	0
I 8	W136	136	12	20	25	0	0	2	4	5
I 10	E 14	15	0	0	0	0	0	0	0	0
I 10	E277	281	0	0	0	0	0	0	0	0
I 10	E302	303	0	0	0	0	0	0	4	4
I 10	E321	321	0	0	0	0	0	0	0	4
I 10	W 14	15	0	0	0	0	0	0	0	0
I 10	W302	303	0	0	0	0	0	0	1	4
I 10	W329	331	0	0	0	0	0	0	0	0
I 17	N263	269	0	0	0	0	0	0	0	0
I 17	S225	230	6	2	0	0	0	0	0	0
I 17	S264	269	0	0	0	0	0	0	0	1
I 19	N 23	24	0	0	0	0	0	2	2	3
I 40	E 49	49	0	0	0	0	0	0	0	0
I 40	E 53	53	0	0	0	0	0	0	0	0
I 40	E145	146	0	0	0	0	0	0	0	0
I 40	E259	268	0	0	0	0	0	0	0	2
I 40	E269	283	0	20	18	0	0	0	0	0
I 40	W 49	49	0	0	0	0	0	0	0	0
I 40	W 53	53	0	0	0	0	0	0	0	1
I 40	W145	146	0	0	0	0	0	0	0	0
I 40	W251	251	0	0	0	0	0	0	0	0
I 40	W269	283	0	10	7	0	0	0	0	0

TABLE 36 ROUGHNESS OF INTERSTATE SECTIONS WITH OVERLAY

ROUTE	MILEPOST		ROUGHNESS														
	BEG	END	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
I 8	E136	136	42	66	75	86	112	100	147	119	131	148	37	71	82	117	116
I 8	W136	136	47	72	64	84	95	84	125	98	148	157	47	67	72	56	112
I 10	E 14	15	23	35	40	48	53	102	69	84	68	118	98	120	146	163	140
I 10	E277	281	96	151	76	81	95	107	115	77	90	84	85	91	98	102	109
I 10	E302	303	48	73	65	74	90	96	112	115	109	114	120	130	122	142	141
I 10	E321	321	71	94	111	123	117	130	138	60	85	88	77	97	93	127	116
I 10	W 14	15	40	68	68	81	92	96	136	198	68	104	74	98	94	123	107
I 10	W302	303	84	63	51	70	86	105	116	127	106	118	132	130	121	148	158
I 10	W329	331	87	77	68	79	99	84	95	47	76	86	79	88	81	97	120
I 17	N263	269	100	131	138	135	157	139	140	156	71	121	97	106	104	120	134
I 17	S225	230	32	46	56	69	84	130	87	117	127	87	83	110	99	100	153
I 17	S264	269	71	86	91	99	120	162	149	144	97	108	95	122	104	126	130
I 19	N 23	24	0	0	0	0	0	0	0	0	52	64	76	82	83	88	114
I 40	E 49	49	0	0	0	0	0	0	0	0	37	61	75	67	60	101	125
I 40	E 53	53	0	58	97	23	0	66	100	157	82	67	92	126	119	165	143
I 40	E145	146	0	0	0	0	0	0	0	44	84	96	82	91	77	124	104
I 40	E259	268	28	57	70	101	139	168	172	122	66	98	93	104	105	145	158
I 40	E269	283	84	139	125	143	158	183	206	222	211	227	91	108	113	148	157
I 40	W 49	49	0	0	0	0	0	0	0	0	52	112	70	71	76	102	117
I 40	W 53	53	0	78	57	78	0	38	113	73	69	120	92	227	90	129	129
I 40	W145	146	0	0	0	0	0	0	0	47	80	108	90	102	94	104	135
I 40	W251	251	0	0	0	0	0	0	0	0	51	83	68	81	85	118	121
I 40	W269	283	85	131	135	134	159	175	213	224	224	234	93	110	125	151	152

TABLE 37 ROUGHNESS EQUATIONS FOR INTERSTATE SECTIONS WITH OVERLAY

ROUTE	MILEPOST BEG	END	Co	C1	Se Const	R2	n	DOF	Se Coef
ARTNODMP		SUBP	23.40	20.40	10.51	0.93	5	3	3.32
I 8	E136	136	35.10	11.90	19.00	0.57	5	3	6.01
I 8	W136	136	71.29	12.64	17.98	0.73	7	5	3.40
I 10	E 14	15	79.00	3.79	4.68	0.79	7	5	0.88
I 10	E277	281	103.43	5.50	5.15	0.86	7	5	0.97
I 10	E302	303	70.86	6.68	11.41	0.66	7	5	2.16
I 10	E321	321	70.43	6.25	14.79	0.50	7	5	2.80
I 10	W 14	15	101.14	7.32	9.06	0.79	7	5	1.71
I 10	W302	303	67.29	5.57	9.97	0.64	7	5	1.88
I 10	W329	331	100.47	3.77	13.12	0.27	6	4	3.14
I 17	N263	269	70.00	13.00	19.18	0.60	5	3	6.07
I 17	S225	230	95.67	5.29	10.86	0.51	6	4	2.60
I 17	S264	269	45.43	8.61	6.55	0.91	7	5	1.24
I 19	N 23	24	42.40	11.17	17.49	0.64	6	4	4.18
I 40	E 49	49	59.47	16.91	17.08	0.81	6	4	4.08
I 40	E 53	53	78.14	3.96	14.87	0.28	7	5	2.81
I 40	E145	146	55.29	13.64	12.23	0.87	7	5	2.31
I 40	E259	268	71.80	17.20	7.55	0.95	5	3	2.39
I 40	E269	283	78.73	3.60	22.78	0.10	6	4	5.45
I 40	W 49	49	129.27	0.54	55.99	0.00	6	4	13.39
I 40	W 53	53	78.86	5.75	13.38	0.51	7	5	2.53
I 40	W145	146	44.29	10.61	11.65	0.82	7	5	2.20
I 40	W251	251	78.50	15.90	6.29	0.96	5	3	1.99

TABLE 38 CRACKING OF STATE HIGHWAY ROUTES WITH OVERLAY

ROUTE	MILEPOST BEG	END	CRACKING 79	80	81	82	83	84	85	86
S 88	E 1	3	0	0	0	0	0	0	0	0
S 408	E274	275	0	24	0	0	0	0	0	0
S 61	N372	381	14	18	0	0	0	0	0	0
S 64	E271	276	0	0	0	0	0	0	2	2
S 71	N103	109	0	0	0	0	0	0	0	0
S 77	N361	363	0	1	1	0	0	0	1	1
S 82	E 15	18	0	23	5	0	0	0	0	0
S 85	N189	189	0	0	0	0	0	0	0	0
S 85	N190	190	0	0	0	0	1	0	0	0
S 86	E167	169	0	0	0	0	0	0	0	0
S 87	N135	145	3	6	2	2	3	3	0	0
S 87	N231	240	0	0	0	0	0	0	0	1
S 87	N241	246	0	0	1	1	1	1	2	2
S 87	S172	172	0	0	0	0	0	0	0	0
S 88	E199	199	0	0	0	0	0	0	0	0
S 90	E322	324	0	0	0	0	0	0	0	1
S260	E378	385	0	0	0	0	0	1	1	1
S260	W340	340	0	0	0	0	10	8	0	12
S277	N336	336	0	0	0	0	0	0	0	1
S279	N288	299	3	0	0	0	0	0	0	0
S287	N120	121	0	0	0	0	0	0	0	0
S287	N122	122	0	0	0	0	0	0	0	0
S377	N 1	6	0	3	0	0	0	0	0	0
S377	N 7	13	0	0	0	1	1	0	0	1
S377	N 14	33	0	0	0	0	0	0	0	0

TABLE 39 ROUGHNESS OF STATE HIGHWAY ROUTES WITH OVERLAY

ROUTE	MILEPOST BEG	END	ROUGHNESS 72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
S 8	BE 1	3	0	0	93	92	138	155	206	143	103	108	110	128	108	133	143
S 40	BE274	275	0	184	206	0	223	230	110	286	0	24	195	186	183	227	234
S 61	N372	381	0	229	242	244	265	304	288	318	340	115	108	134	134	136	128
S 64	E271	276	264	290	352	300	306	308	316	147	162	185	174	189	190	173	210
S 71	N103	109	179	182	220	234	226	204	240	107	112	123	115	144	149	136	141
S 77	N361	363	241	274	293	254	284	328	339	358	151	156	145	158	156	155	143
S 82	E 15	18	140	148	153	176	184	178	179	0	228	240	135	152	151	141	155
S 85	N189	189	135	159	179	198	199	173	231,	145	141	159	158	182	187	226	189
S 85	N190	190	0	0	203	226	230	218	288	148	151	174	195	196	223	203	240
S 86	E167	169	94	78	78	95	116	130	0	0	63	0	73	99	97	123	115
S 87	N135	145	0	213	227	190	221	204	233	104	50	87	84	103	108	116	100
S 87	N231	240	202	230	223	208	206	229	236	250	65	92	99	122	120	140	120
S 87	N241	246	194	217	90	64	98	93	96	97	102	140	118	141	132	152	133
S 87	S172	172	0	159	142	252	137	122	220	0	0	0	243	0	0	235	257
S 88	E199	199	286	283	340	355	295	338	326	146	142	161	152	171	182	151	173
S 90	E322	324	75	79	81	68	94	89	87	93	49	76	64	69	73	75	72
S260	E378	385	209	309	271	268	296	316	308	83	79	109	111	135	112	143	125
S260	W340	340	0	0	0	0	177	409	400	0	100	89	14	17	252	320	244
S277	N336	336	307	436	471	385	418	466	510	190	167	206	180	207	192	216	209
S279	N288	299	68	74	86	103	101	104	117	116	70	83	79	91	76	90	102
S287	N120	121	0	0	270	246	272	250	284	26	36	38	50	62	80	85	66
S287	N122	122	0	0	242	213	257	249	283	42	33	66	73	93	117	111	80
S377	N 1	6	0	337	391	363	395	450	342	365	272	103	104	117	108	130	114
S377	N 7	13	0	304	353	336	340	378	345	366	76	90	91	111	104	131	107
S377	N 14	33	0	315	354	359	360	411	369	396	81	95	100	118	113	133	113

TABLE 40 ROUGHNESS EQUATIONS FOR THE STATE HIGHWAY ROUTES WITH OVERLAY

ROUTE	MILEPOST BEG	END	Co	C1	Se Cons	R2	n	DOF	Se Coef
S 8B	E 1	3	113.00	2.00	17.17	0.09	8	6	2.65
S 40B	E274	275	169.30	11.90	16.87	0.62	5	3	5.34
S 61	N372	381	110.93	4.26	9.48	0.47	6	4	2.27
S 64	E271	276	150.57	6.26	12.55	0.64	8	6	1.94
S 71	N103	109	103.46	5.54	9.42	0.71	8	6	1.45
S 77	N361	363	154.14	-0.54	6.32	0.04	7	5	1.20
S 82	E 15	18	138.10	2.90	8.18	0.30	5	3	2.59
S 85	N189	189	128.32	10.01	15.05	0.76	8	6	2.32
S 85	N190	190	134.89	12.52	11.25	0.90	8	6	1.74
S 86	E167	169	69.00	10.80	10.28	0.79	5	3	3.25
S 87	N135	145	73.43	4.57	18.73	0.29	8	6	2.89
S 87	N231	240	68.00	10.07	13.06	0.77	7	5	2.47
S 87	N241	246	100.04	5.96	13.92	0.56	8	6	2.15
S 87	S172	172	Insufficeint data						
S 88	E199	199	142.82	3.76	11.87	0.41	8	6	1.83
S 90	E322	324	72.50	-0.25	13.31	0.00	8	6	2.05
S260	E378	385	77.46	7.70	13.58	0.69	8	6	2.10
S260	W340	340	-47.29	39.29	86.47	0.59	8	6	13.34
S277	N336	336	176.43	4.32	13.87	0.40	8	6	2.14
S279	N288	299	69.14	3.82	7.55	0.59	7	5	1.43
S287	N120	121	19.86	7.89	9.94	0.82	8	6	1.53
S287	N122	122	32.46	9.87	19.27	0.65	8	6	2.97
S377	N 1	6	100.27	3.54	8.54	0.43	6	4	2.04
S377	N 7	13	74.57	6.71	11.20	0.67	7	5	2.12
S377	N 14	33	81.14	6.61	10.13	0.70	7	5	1.91

TABLE 41 CRACKING OF U.S. HIGHWAY ROUTES WITH OVERLAYS

ROUTE	MILEPOST BEG	END	CRACKING 79	80	81	82	83	84	85	86
U 60 E	152	152	0	0	0	0	0	0	0	0
U 60 E	276	286	0	16	0	0	0	0	0	0
U 60 E	310	315	3	2	0	0	0	0	0	0
U 60 E	316	331	0	0	0	0	0	0	1	1
U 60 E	332	335	0	0	0	0	0	0	0	1
U 60 E	340	341	0	0	0	0	0	0	0	0
U 60 W	152	152	0	0	0	0	0	0	0	0
U 70 E	288	292	0	0	0	0	0	0	0	0
U 70 E	339	340	0	0	0	0	1	1	1	1
U 89 N	70	70	0	0	0	0	0	0	0	0
U 89 N	75	79	0	0	0	0	0	0	0	1
U 89 N	93	111	0	0	0	0	0	0	0	0
U 89 N	346	353	0	0	0	0	0	0	0	0
U 89 N	525	525	0	0	1	1	2	1	2	2
U 89 N	526	526	0	0	0	0	0	0	0	1
U 89 N	525	531	0	0	1	1	2	1	2	2
U 89 S	70	70	0	0	0	0	0	0	0	0
U 89 S	75	79	0	0	0	0	1	1	2	1
U 89AN	580	593	0	0	0	0	0	0	2	1
U 89AN	594	599	0	10	0	0	0	0	0	1
U 89AN	600	613	0	11	0	0	0	0	1	1
U 93 S	100	111	20	0	0	0	0	0	1	2
U160 E	373	382	0	0	0	0	1	1	1	3
U163 N	395	395	0	7	0	0	0	0	0	0
U191 N	44	51	0	1	2	4	4	1	1	1
U191 N	104	108	0	6	13	14	11	2	2	3
U666 E	30	38	0	0	0	0	0	0	0	1
U666 E	196	204	0	0	0	0	0	0	0	0
U666 E	205	220	0	0	0	0	0	0	0	0
U666 W	157	158	0	0	0	0	0	0	0	10
U666 W	159	159	0	0	0	0	0	0	0	15
U666 W	160	160	0	0	0	0	0	0	0	15

TABLE 42 ROUGHNESS OF U.S. HIGHWAY ROUTES WITH OVERLAYS

ROUTE.MILEPOST				ROUGHNESS														
		BEG	END	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
U 60	E	152	152	0	293	331	299	395	23	0	0	489	112	126	116	118	130	117
U 60	E	276	286	129	150	137	134	157	139	176	175	194	96	95	116	107	128	103
U 60	E	310	315	204	215	202	224	199	235	215	225	218	121	120	138	140	144	137
U 60	E	316	331	213	229	192	183	190	229	204	208	57	82	82	101	109	115	101
U 60	E	332	335	0	280	121	120	138	168	149	143	80	104	107	126	128	138	132
U 60	E	340	341	0	185	172	114	142	162	217	213	116	130	148	162	241	260	153
U 60	W	152	152	0	293	331	312	400	23	349	393	399	224	297	152	152	137	226
U 70	E	288	292	152	118	108	99	138	152	141	163	41	58	67	88	85	124	96
U 70	E	339	340	208	223	170	124	135	176	160	190	143	144	80	104	109	142	137
U 89	N	70	70	0	233	243	273	290	327	291	227	149	189	194	175	176	208	222
U 89	N	75	79	122	131	155	158	159	175	190	228	73	95	86	107	79	103	96
U 89	N	93	111	125	161	147	148	150	164	168	65	64	71	85	107	100	119	99
U 89	N	346	353	87	87	99	115	134	128	115	139	93	122	120	130	126	131	144
U 89	N	525	525	85	95	96	107	116	107	122	128	101	83	82	103	100	115	148
U 89	N	526	526	184	165	166	150	159	172	196	196	96	84	89	114	102	118	146
U 89	N	525	531	85	95	96	107	116	107	122	128	101	83	82	103	100	115	148
U 89	S	70	70	0	233	243	273	290	327	0	0	109	139	145	149	168	149	179
U 89	S	75	79	122	131	155	158	159	175	0	0	67	87	69	107	114	126	101
U 89A	N	580	593	138	171	175	200	210	200	210	225	84	62	69	91	101	102	132
U 89A	N	594	599	141	167	198	225	238	244	221	246	210	94	92	116	116	113	132
U 89A	N	600	613	142	171	168	204	224	206	194	213	195	69	60	85	87	90	146
U 93	S	100	111	196	190	206	216	222	220	223	237	90	84	88	94	91	96	126
U160	E	373	382	156	153	169	156	173	190	192	201	86	77	83	104	99	114	122
U163	N	395	395	212	246	222	221	239	153	249	259	259	105	117	123	127	121	153
U191	N	44	51	0	186	203	193	214	221	232	242	89	109	87	115	125	130	126
U191	N	104	108	0	207	195	187	204	218	221	136	128	136	121	163	169	168	166
U666	E	30	38	203	208	205	203	216	228	250	286	80	107	98	121	125	123	113
U666	E	196	204	0	320	350	346	338	384	343	443	387	135	121	140	131	160	145
U666	E	205	220	0	308	348	336	318	374	331	167	136	157	147	174	157	171	169
U666	W	157	158	76	86	94	85	102	142	0	0	0	41	51	74	72	101	65
U666	W	159	159	66	74	85	75	99	136	0	0	0	35	50	65	74	142	63
U666	W	160	160	61	68	67	69	85	124	0	0	0	0	197	0	0	213	226

TABLE 43 ROUGHNESS EQUATIONS FOR THE U.S. HIGHWAY ROUTES WITH OVERLAYS

ROUTE	MILEPOST BEG	END	Co	C1	Se Cons	R2	n	DOF	Se Coef
ARTNO	DMP	SUBPR	115.93	1.11	7.20	0.09	6	4	1.72
U 60 E	152	152	95.00	3.57	12.02	0.28	6	4	2.87
U 60 E	276	286	117.93	4.40	6.79	0.65	6	4	1.62
U 60 E	310	315	126.11	-4.27	47.12	0.05	8	6	7.27
U 60 E	316	331	103.46	3.62	20.70	0.18	8	6	3.19
U 60 E	332	335	143.21	7.70	53.78	0.13	8	6	8.30
U 60 E	340	341	Conflicting data						
U 60 W	152	152	87.68	0.57	41.81	0.00	8	6	6.45
U 70 E	288	292	68.80	15.20	9.71	0.89	5	3	3.07
U 70 E	339	340	181.68	2.40	27.52	0.05	8	6	4.25
U 89 N	70	70	80.14	2.79	11.97	0.23	7	5	2.26
U 89 N	75	79	55.43	7.40	10.67	0.77	8	6	1.65
U 89 N	93	111	112.39	2.94	14.78	0.22	8	6	2.28
U 89 N	346	353	72.71	7.96	15.68	0.59	7	5	2.96
U 89 N	525	525	74.00	8.25	12.52	0.71	7	5	2.37
U 89 N	526	526	72.71	7.96	15.68	0.59	7	5	2.96
U 89 N	525	531	47.04	18.38	36.57	0.64	8	6	5.64
U 89 S	70	70	23.82	13.35	24.43	0.68	8	6	3.77
U 89 S	75	79	55.00	9.14	13.66	0.71	7	5	2.58
U 89AN	580	593	85.20	7.23	7.57	0.80	6	4	1.81
U 89AN	594	599	41.80	13.63	17.74	0.72	6	4	4.24
U 89AN	600	613	76.29	4.82	10.21	0.56	7	5	1.93
U 93 S	100	111	69.57	7.07	7.47	0.83	7	5	1.41
U160 E	373	382	98.73	7.31	9.13	0.74	6	4	2.18
U163 N	395	395	84.29	6.82	10.55	0.70	7	5	1.99
U191 N	44	51	118.86	6.56	12.90	0.64	8	6	1.99
U191 N	104	108	87.00	5.64	11.70	0.57	7	5	2.21
U666 E	30	38	122.87	4.51	11.45	0.40	6	4	2.74
U666 E	196	204	148.18	2.57	12.46	0.23	8	6	1.92
U666 E	205	220	40.53	7.66	16.88	0.47	6	4	4.03
U666 W	157	158	29.00	12.14	32.81	0.37	6	4	7.84
U666 W	159	159	Insufficeint data						

construction. The following discussion of the performance of overlays considers only the 3 and 4 inch overlays since these pavements should be comparable to the SAMI treatment.

Interstates With Overlays

Four of the interstate sections have overlays of 3 to 4 inches:

I8E, MP 136

I10E, MP 277-281

I17N, MP 263-269

I17S, MP 225-230

None of these sections have developed cracking since the overlay was placed. The roughness of the sections the year before the overlay was placed ranges from 84 to 156. Immediately following the overlay the roughness ranges from 37 to 87. The rate of change in roughness ranged from 3.8 to 20.4. The R^2 for the regression equations ranges from 0.27 to 0.93 with two sections having an R^2 of more than 0.7.

Comparison of the overlays with SAMI sections for interstate sections shows both treatments have controlled cracking and the average rate of change in roughness is in the same range for the two types of treatments.

State Highway Sections with Overlays

Six state highway sections have overlays in the range of 3 to 4 inches:

S64E, MP 271-276

S85N, MP 183

S85N, MP 190

S279N, MP 288-299

S377N, MP 1-6

S377N, MP 14-33

None of these sections have developed significant amounts of cracking since the overlay was placed. In fact, only one of the overlays placed on State Highways from 1979 to 1982 has developed over 10 percent cracking, all other sections have less than 2 percent cracking. The roughness of the sections the year before the overlay was placed on the six sections ranged from 116 to 396 inches per mile. Following the overlay the range of roughness was 70 to 147. The range in the rate of change in roughness for the state highway sections was 3.8 to 12.5. The R^2 for these equations ranged from 0.43 to 0.90.

Both the SAMI and overlay treatments have been successful in preventing cracking on the sections studied. The rate of change in roughness is in the same range for the two treatments.

U.S. Highway Sections with Overlays

Five U.S. Highway routes received 3 to 4 inch thick overlays in 1979 to 1982:

U70E, MP 288-292

U89N, MP 526

U89AN, MP 594-599

U89AN, MP 600-613

U666E, MP 30-38

All of these sections have one percent cracking or less. In fact, the cracking level is 15 percent at two mile posts and 10 percent at two miles posts of the U.S. Highway sections with overlays from 1979 to 1982. All other sections had less than three percent cracking in 1986. The range of roughness of these sections before the overlay was 163 to

286 inches per mile. Following the overlay the range was reduced to 41 to 96 inches per mile. The rate of change in roughness for these sections was in the range of 4.5 to 15.2 inches per mile per year.

Comparison of the overlay and SAMI treatments on U.S. highway routes show both treatments have similar performance with respect to cracking and the rate of change in roughness.

SUMMARY OF THE PERFORMANCE OF CONVENTIONAL TREATMENTS

The data in the pavement management system data base were very useful for the analysis of the performance of seal coats and overlays. Overall the performance of the asphalt-rubber membranes and the conventional treatments was very comparable. All of the treatments are performing well with respect to both cracking and the rate of increase of roughness. Nothing was discovered in this analysis that would indicate one type of treatment is performing better than the other treatments. However, the analysis did not consider the condition of the pavement at the time of the treatment. Mr. Gene Morris reported that the SAMs and SAMIs were only placed on severely distressed pavements where a conventional treatment would fail. If this is the case, then one should conclude that each of the treatments performed well within its design situation.

CHAPTER V COST EFFECTIVENESS OF ASPHALT-RUBBER, SUMMARY, AND RECOMMENDATIONS

A comprehensive life-cycle cost analysis of a pavement design alternative requires an extensive amount of information about cost, pavement performance and traffic data. In a research project for the Pennsylvania Department of Transportation, Zaniewski et al. developed a project level pavement rehabilitation design system which optimizes the selection of resurfacing strategies based on minimizing the present worth costs of pavement resurfacing strategies (Ref. 23). The evaluation methodology developed for Pennsylvania incorporates models for:

1. Predicting critical pavement response
2. Predicting fatigue life
3. Estimating the years of service based on traffic estimates
4. Distress prediction
5. Costs Analysis
    a) traffic delay costs
    b) overlay construction costs
        - site-establishment
        - surface-preparation
        - overlay placement
        - shoulder placement
    c) maintenance costs
    d) value of extended life
    e) salvage value
6. Net preset value

7. Optimization

This comprehensive model could not be used during this project because generating the required input data requires more effort than was available.

Fortunately, comparing the cost effectiveness of asphalt-rubber to conventional materials does not requires such a comprehensive model. Economic analyses are only sensitive to cost and performance differentials. As discussed in Chapter I, construction of SAM and SAMI layers uses conventional equipment and procedures. Therefore, the major impact of the asphalt-rubber is the cost of materials. Rather than examining all of the components of the cost of SAMs and SAMIs, cost data were obtained from CRAFTCO Inc. on the turn key construction costs. To account for the economies of scale cost data were obtained from projects of 2 and 10 miles.

There are several economic analysis methods available for balancing the stream of costs associated with each alternative. For this analysis the present worth method is used:

$$TPWC_x = ICC_x + \sum_{t=1}^{t=n} pwf_{t,i}(FCC_{t,x} + MO_{t,x} + UC_{t,x}) - pwf_{n,i}\, SV_x$$

where:

$TPWC_x$ = Total Present Worth of Costs for alternative x

ICC_x = Initial Construction Costs for alternative x

$pwf_{t,i}$ = present worth factor at year t for discount rate i

$$pwf_{t,i} = 1/(1 + i)^t$$

$FCC_{t,x}$ = Future Construction Cost in year t for alternative x

$MO_{t,x}$ = Maintenance and Operation costs in year t for alternative x

$UC_{t,x}$ = User Costs in year t for alternative x

SV_x = Salvage Value of alternative x at the end of the analysis period.

The initial construction cost data are in Table 44. Economic analyses are performed in constant dollar terms so the effect of inflation can be ignored. Therefore, the values in Table 44 can be used for future construction cost estimates.

The pavement management system data base contains the three year average pavement maintenance costs at each mile post. These data were analyzed to determine if there was a correlation between the maintenance costs and other factors such as traffic, roughness, cracking, and year since the pavement received one of the four treatments analyzed in this report. No trends were discovered in the analysis so the average maintenance cost was computed for the four treatment types and three highway types. These average maintenance costs are given in Table 45. The average maintenance costs per mile ranged from $534 per mile on the U.S. Highway sections with seal costs to $1839 per mile for the State highway routes that have overlays. If inflation is considered, these maintenance costs are comparable to the figure reported by Vallegra et. al (Ref. 18) in 1975 of $622/mile/year for a flexible pavement. However, the Vallegra reference reported an annual maintenance cost of $22/mile on a SAMI section. The analysis of the PMS database does not support a large differential in the maintenance costs on asphalt-rubber

TABLE 44 COST DATA FOR THE ECONOMIC ANALYSIS ($/SY)

TREATMENTS	2 MILE PROJECT	10 MILE PROJECT
SAM	1.99	1.84
SAMI 1" COVER	3.80	3.43
SAMI 2" COVER	5.47	4.16
SEAL COAT	1.25	1.07
OVERLAY 1"	1.96	1.73
OVERLAY 2"	3.63	2.46
OVERLAY 4"	6.97	3.92

TABLE 45 AVERAGE MAINTENANCE COSTS PER MILE

	INTERSTATE	STATE HIGHWAYS	U.S. HIGHWAYS
SAM	1490	935	1312
SAMI	1024	1624	1257
SEAL COAT	1238	1550	534
OVERLAY	961	1839	1177

versus conventional treatments. The values in Table 45 were used in the economic analysis.

User costs can be computed for each year of operation. However, the predominant influence of the user costs is during construction projects. For this analysis, use delay operating costs were computed using the procedure developed by Zaniewski et al. for the Federal Highway Administration (Ref. 24). A speed change cycle of 55 to 0 to 55 mph with an average delay of three minutes was assumed. Traffic was assumed to be 95% medium size automobiles and 5% 3 axle single unit trucks. Traffic volumes of 1000 and 10,000 ADT were assumed. A delay period of 2 days was assumed for project set up and tear down and production was assumed to be a mile per day. (The 2 mile project delays traffic for 4 days and the 10 mile project delays traffic for 12 days).

The salvage value was assumed to be 10% of the initial construction cost.

The results of the economic analysis are shown in Table 46. In general, this analysis demonstrates that the longer a treatment lasts the more economical it is as is expected. Comparison of the SAM with a seal coat indicates that if the surface treatment lasts five years, then the SAM needs to last ten years in order to offset the higher initial cost of the SAM. A similar conclusion is obtained comparing a SAMI with a 2" overlay. The comparison of the SAMI with 2 inches cover to a 4 inch overlay showed the SAMI has a lower life cycle cost for the 2 mile project while the costs were about equal for the 10 mile project. The performance analysis performed during this research could not detect a difference between the two treatment types. Hence, cost would be the deciding factor in the selection of the treatment type.

TABLE 46 ECONOMIC ANALYSIS OF ALTERNATIVE TREATMENTS
(NET PRESENT VALUE, DOLLARS PER SQUARE YARD)

PROJECT LENGTH	TREATMENT	ROUTE TYPE	1,000 ADT 5 YRS	1,000 ADT 10 YRS	1,000 ADT 25 YRS	10,000 ADT 5 YRS	10,000 ADT 10 YRS	10,000 ADT 25 YRS
2 MILE	SAM	I	6.75	4.66	3.06	7.12	4.82	3.06
		S	6.37	4.23	2.60	6.74	4.39	2.60
		U	6.63	4.52	2.91	7.00	4.68	2.91
	SAMI 1"	I	11.60	7.48	4.34	11.98	7.65	4.34
		S	12.01	7.94	4.84	12.39	8.10	4.84
		U	11.76	7.66	4.53	12.14	7.82	4.53
	SAMI 2"	I	16.37	10.42	5.88	16.75	10.58	5.88
		S	16.79	10.88	6.37	17.16	11.04	6.37
		U	16.53	10.60	6.07	16.91	10.76	6.07
	SEALCOAT	I	4.46	3.16	2.17	4.84	3.32	2.17
		S	4.68	3.40	2.43	5.05	3.56	2.43
		U	3.98	2.62	1.59	4.35	2.79	1.59
	OL 1"	I	6.30	4.20	2.60	6.68	4.36	2.60
		S	6.90	4.87	3.32	7.28	5.03	3.32
		U	6.45	4.37	2.77	6.82	4.53	2.77
	OL 2"	I	11.07	7.14	4.13	11.45	7.30	4.13
		S	11.68	7.81	4.86	12.05	7.97	4.86
		U	11.22	7.30	4.31	11.60	7.46	4.31
	OL 4"	I	20.62	13.01	7.21	20.99	13.17	7.21
		S	21.22	13.68	7.93	21.59	13.84	7.93
		U	20.77	13.18	7.38	21.14	13.34	7.38
10 MILE	SAM	I	6.41	4.43	2.92	7.53	4.91	2.92
		S	6.02	4.00	2.46	7.14	4.49	2.46
		U	6.28	4.29	2.77	7.40	4.78	2.77
	SAMI 1	I	10.63	6.87	4.00	11.75	7.35	4.00
		S	11.04	7.33	4.49	12.16	7.81	4.49
		U	10.79	7.05	4.19	11.91	7.53	4.19
	SAMI 2	I	12.71	8.15	4.67	13.83	8.64	4.67
		S	13.13	8.61	5.17	14.25	9.10	5.17
		U	12.87	8.33	4.86	13.99	8.82	4.86
	SEALCOAT	I	4.03	2.88	2.01	5.15	3.37	2.01
		S	4.25	3.12	2.26	5.37	3.61	2.26
		U	3.55	2.34	1.42	4.67	2.83	1.42
	OL 1"	I	5.73	3.83	2.38	6.85	4.32	2.38
		S	6.33	4.50	3.11	7.45	4.99	3.11
		U	5.88	4.00	2.56	7.00	4.48	2.56
	OL 2"	I	7.81	5.12	3.06	8.93	5.60	3.06
		S	8.42	5.79	3.78	9.54	6.27	3.78
		U	7.96	5.28	3.23	9.08	5.77	3.23
	OL 4"	I	11.99	7.68	4.40	13.11	8.17	4.40
		S	12.59	8.35	5.12	13.71	8.84	5.12
		U	12.13	7.85	4.58	13.25	8.33	4.58

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APPENDIX A

SUMMARY OF THE PAVER FLEXIBLE PAVEMENT SURVEY PROCEDURE

PAVEMENT CONDITION SURVEY METHOD

Evaluation of the test sections for research work requires a carefully established and thoroughly planned pavement condition evaluation method. There are several pavement condition survey methods used by the different highway agencies. However, the PAVER method is the most widely used, and has been be adopted by the Long Term Pavement Performance studies of the Strategic Highway Research Program. Therefore, the PAVER pavement condition survey method should be adopted for the research of pavement performance by ADOT.

Overview of PAVER Pavement Condition Survey Method

The PAVER system was developed by M. Y. Shahin and S. D. Kohn of the Construction Engineering Research Laboratory of the Corps of Engineers. The initial development was for the evaluation of air field pavements. Subsequently, PAVER was adopted for the evaluation of roads and parking lots on military bases and forts. The American Public Works Association then selected the PAVER system for use by local highway agencies.

The PAVER system includes several computer programs for the analysis of the pavement condition data and manipulation of the data base. There are models for the determination of the composite pavement condition score, called the pavement condition index, PCI, the determination of future pavement maintenance requirements, budgets, etc. However, the only part of the PAVER system we are concerned with at this time is the pavement condition survey procedure for flexible pavements. There is a comparable procedure for the evaluation of rigid pavements that can be adopted at a future time if necessary.

Compared to other pavement condition survey methods, the PAVER method is extremely detailed. Some condition survey methods only recognize two distress types and are performed while traveling at high speeds; whereas, the PAVER procedure defines 19 distress types, each at three levels of severity, and the extend of the distress is actually measured and recorded as linear or square feet.

Sampling

Due to the detailed level of data collection for the condition survey, data collection for the entire pavement surface is impractical. The pavements which are going to be evaluated are divided into sections, which are homogeneous with respect to inventory data such as layer thicknesses, materials and traffic. For our purposes, the sections will be the research-experimental projects, the asphalt-rubber projects or the control sections. Each section is subdivided into sample units, which are the smallest component of the pavement network. The sample units are used for inspection purposes to determine the distress and condition of the sections. Sample units for flexible pavements can range in size from 1500 to 3500 sf. with a recommended average of 2500 sf.

The PAVER manual presents a sampling procedure for reducing the amount of surface area that needs to be surveyed. The percent of a pavement section that needs to be surveyed depends on the use of the data. The PAVER manual addresses the needs of the network and project level decision process. There are no recommendations in the PAVER condition survey manual for research work. For network level decisions, the manual specifies the number of sample units that should be surveyed based on the number of sample units in the section; in general, PAVER requires a sampling rate of 15 to 25 percent. For project level evaluation, the required sampling rate is a function of the number of sample units in the section and the variability of the pavement condition index for the section. For example, if the section has 20 sample units, the expected range in the pavement condition index is 25, then 9 sample units should be surveyed in order to have the recommended confidence level. If the 9 sample units are surveyed and the range in PCI was found to be 40, then the number of sample units should be increased to 13. The number of sample units required was calculated based on a 95 percent confidence that the error in the pavement condition index is within ±5 points. According to the PAVER documentation, this confidence level is adequate for contracting for maintenance services and recording all distresses/severity/density is not recommended.

Data Collection and Training

The condition survey should be performed by a two-person crew, a third person is recommended for high traffic volume situations. One crew member measures and calls out the distress and the other member records the data. The recorder and measurer task should be rotated every few hours. General-education college students are usually good inspectors.

Training usually consists of reading material in advance of classroom training, two to four hours of classroom training and two to five days of field work actually rating pavement sections. The observation crews were given the rating manual three days before the classroom training and told they would be tested at the start of the training session. The classroom training covered the need for performing the survey, filling out the survey form and a definition of the pavement distresses. In the field, crews are required to rate pavement sections until the PCI computed from the data are consistently within ± 5 points.

The inspection crew needs to be equipped with a hand odometer for measuring distress lengths and a ten-foot straight edge for measuring distortions in the pavement surface, such as rut depth. In addition, the data collectors need a supply of forms, a clip board, pencils, and the pavement condition rating manual. The crew should also be provided hard hats and safety vests.

The actual data collection requires the survey crew to first mark the sample units, then measure and record each of the distresses on the data collection form, then transfer the data to the computer. The data for each sample unit is recorded on a separate data collection form as shown on Figure 1.

Distress Definitions

There are 19 distress types defined for flexible pavements. Each of these are rated according to severity and extent. The PAVER Pavement Condition Index Field Manual has both verbal and photographic definitions of the distresses.

Alligator Cracking - Repeated loading of the pavement surface causes cracking to develop at the bottom of the asphalt concrete or stabilized base layer where the tensile strains are the highest. The cracks propagate to the surface initially as a series of parallel longitudinal cracks. After repeated traffic loadings, the cracks connect, forming many-sided, sharp-angle pieces in a pattern that resembles chicken wire or alligator skin. The pieces are generally less than 2 ft. on the longest side.

By definition, alligator cracks are caused by traffic, and, therefore, only occur in the wheel paths and not over the entire pavement area. (Pattern-type cracking which occurs over the entire area that is not subjected to traffic loading is defined as block cracking.)

Alligator cracking is considered a major structural distress and is usually accompanied by rutting. When alligator cracking and rutting occur in the same area, each is recorded separately at its respective severity level.

Low severity alligator cracking is fine-longitudinal cracks that are parallel to each other with few if any of the cracks connected. The material along the sides of the cracks is in tack, e.g. the cracks are not spalled.

Medium severity alligator cracking shows a pattern or network of cracks that may be slightly spalled.

High severity alligator cracks have well-defined pieces that may rock under traffic. The edges of the cracks are spalled.

Alligator cracking is measured in square feet of surface area. The major difficulty in measuring alligator cracking is there are usually two or three levels of severity existing within one distressed area. If the areas with the different levels of severity can be easily distinguished, then each should be measured and recorded separately. However, if the areas of different levels of distress cannot be readily distinguished, the entire area is rated at the highest severity level.

<u>Bleeding</u> - Excess asphalt on the surface of the pavement is called bleeding. It may be the result of excessive asphalt cement in the mix,

excess application of a bituminous sealant, and/or a low void content. It occurs when asphalt fills the voids of the mix during hot weather and then expands onto the pavement surface. The result is a film of bituminous material on the pavement surface which creates a shiny, glass-like surface that becomes sticky in hot weather.

Low level bleeding is noticeable only during a few days of the year. The asphalt does not stick to shoes and vehicles do not leave tread patterns in the asphalt. For moderate bleeding, the surface of the pavement will be sticky to shoes and vehicles for a few weeks during the year. Pavements with high severity bleeding will show tire tread marks several weeks a year.

Bleeding is measured in square feet of surface area. A pavement cannot have both bleeding and polished aggregates.

Block Cracking - Shrinkage of the asphalt concrete and daily temperature cycles may cause the surface to crack into rectangular pieces ranging in size from 1 by 1 ft. to 10 by 10 ft. It generally occurs over a large area of the pavement, and sometimes the kneading action of traffic will cause the block cracks to heal. Block cracking generally indicates the asphalt has hardened significantly.

The severity of block cracking is rated according to the severity of the cracks and not by the size of the blocks. Low severity block cracking is either unfilled cracks smaller than 3/8 in. or satisfactorily filled cracks. Medium severity block cracks are either nonfilled cracks 3/8 to 3 in. wide or any crack with light random cracking. High severity block cracks are any crack surrounded by medium to high severity random cracks or where the pavement a few inches around the crack is severely broken or any unfilled crack that is wider than 3 in.

Block cracking is measured in square feet of surface area. Usually, block cracking only has one severity level in any distressed area; however, if there are two areas of the sample unit with different severity levels, each area is measured and recorded separately.

Bumps and Sags - Bumps are small, localized upward displacements of the pavement surface. They can be caused by several factors:

1. Buckling or bulging of an underlying portland cement concrete surface that has been overlaid with asphalt concrete.
2. Frost heave
3. Infiltration and buildup of material in a crack in combination with traffic loading, sometimes called tenting.

Sags are small, abrupt downward displacements of the pavement surface. Distortions and displacements which occur over large areas of the pavement surface, causing large and/or long dips in the pavement are swells. If the bumps appear in a pattern perpendicular to traffic flow and are spaced less than 10 ft., the distress is called corrugations.

The severity of bumps and sags are rated according to the affect on ride quality. Slight bumps and sags cause the vehicle to bounce slightly, but create little discomfort. For medium severity, vehicle vibrations are significant and the vehicle will bounce significantly, creating some discomfort. High severity bumps and sags cause the vehicle to bounce excessively, creating substantial discomfort and a safety hazard.

Bumps and sags are measured in linear feet. If a crack occurs in combination with a bump, both are recorded.

Corrugations - Traffic action on an unstable pavement surface can cause a series of closely spaced ridges at fairly regular intervals less than 10 ft. are called corrugations. The ridges are perpendicular to the traffic flow.

The severity of the corrugations are rated according to their impact on ride quality. The criteria for low, medium and high severity are the same as for bumps and sags. The extent is measured in square feet of the surface area.

Depressions - Localized pavement surface areas with elevations slightly lower than the surrounding pavement are called depressions. They are most noticeable after a rain when they appear as birdbath areas. They are caused by either subsidence of the foundation soil or improper construction. They can cause some roughness and when filled with water, they may promote hydroplaning. Depressions are distinguished from sags by the gentle rather than abrupt change in elevation.

The severity of depressions is rated by depth. Low severity depressions are one-half to one in. Medium severity are one to two inches and high severity are more than two in.

The extent of a depression is measured in square feet.

Edge Cracking - Cracks within one to two feet of the pavement's edge and parallel with the edge are called edge cracking. They are the result of traffic loadings near the pavement edge, particularly when the support of the subgrade and base is reduced either through a high moisture content or by frost action. If the area between the pavement edge and the crack is broken up, it is referred to as being raveled.

The severity of edge cracking is defined according to the severity of the cracks and whether or not the area between the cracks and the pavement edge is raveled or broken up. Low severity edge cracking has low or medium severity cracking and no raveling or breaking up of the area between the cracks and the pavement edge. Medium cracks are unfilled cracks up to three inches wide or any filled crack, in either case, there can only be slight random cracking around the main cracks. Medium severity edge cracking has medium severity cracking with some breaking up or raveling. High severity edge cracks have considerable breakup or raveling along the pavement edge.

The extent of edge cracking is measured in linear feet.

Joint Reflection Cracking - By definition, reflection cracking only occurs on asphalt concrete overlays of portland cement concrete pavements. Therefore, one must know the original pavement is concrete before reflection cracks can be identified. Knowing the dimensions of the original slab assist in identification of this distress.

The severity levels are the same as defined for longitudinal and transverse cracking. The extent of reflection cracking is measured in linear feet. The severity and extent of each individual crack is recorded separately.

Lane/Shoulder Drop-off - A difference in elevation between the pavement shoulder and the pavement edge may be caused by shoulder erosion, shoulder settlement, or by building up of the pavement without adjustments to the shoulder elevation. The severity is rated by the amount of drop-off. Low severity drop-off is one to two inches. Medium severity is two to four inches and high severity drop-off is anything more than four inches. The extent is measured in linear feet.

Longitudinal and Transverse Cracking - Longitudinal cracks, parallel to the pavement's centerline may be caused by:

1. A poorly constructed pavement lane joint.
2. Shrinkage of the asphalt concrete due to low temperatures or hardening of the asphalt and/or daily temperature cycling.
3. A reflective crack caused by cracking beneath the surface course, including cracks in PCC slabs but not joints.

Transverse cracks extend across the pavement at approximately right angles to the centerline. They may be caused by either condition 2 or 3 above. In general, longitudinal and transverse cracks caused by environmental conditions rather than traffic loading.

The severity levels for transverse and longitudinal cracking are:

Low severity - Nonfilled cracks less than 3/8 in. wide or any filled crack with the filler in satisfactory condition.

Medium severity - Light random cracking along the sides of any nonfilled crack up to three inches wide or any filled crack. Any nonfilled crack 3/8 to 3 inches wide.

High severity - Any nonfilled crack over three inches wide. Any crack with medium or severe random cracking or where the pavement around the crack is severely broken.

The extent of the cracking is measured in linear feet. Cracks displaying multiple severity levels are recorded as separate cracks.

Bumps or sags occurring at the cracks are also recorded as separate distresses.

<u>Patching and Utility Cut Patching</u> - A patch is an area of the pavement that has been replaced with a new material. All patches are treated as distresses regardless of how well the patch is performing. The severity of the patch is rated according to ride quality and the condition of the patch. Distresses in a patch are <u>not</u> recorded separately, e.g., if the patch is badly cracked, it is recorded as a hign severity level patch but no record is made of the cracking.

Low severity patches are in good condition and have little, if any, effect on the ride. Medium severity patches are showing moderate deterioration and cause a vehicle to bounce slightly creating some discomfort. High severity patches are badly deteriorated and/or ride quality is seriously affected creating discomfort and possible safety problems or damage to the vehicle.

The square feet of patched area is measured. If a patch displays multiple severity levels, each area with different severity is recorded as a separate patch.

<u>Polished Aggregate</u> - Close examination of the pavement surface is required to determine if the surface of the aggregate is smooth and the aggregate do not extend above the surface which are the primary indicators of a polished surface. This type of distress is indicated when the skid resistance test is low or has dropped significantly from previous ratings.

The severity of polishing is not rated. The extent of the polished area is measured in square feet. If bleeding is observed, polishing should not be counted.

<u>Potholes</u> - Potholes are bowl-shaped depressions in the pavement surface less than three feet in diameter. They are a structurally related distress produced when traffic abrades small pieces of the pavement surface. The disintegration continues due to poor mix design, weak spots in the base or subgrade, or because of high severity alligator cracking. Holes caused by high severity alligator cracking should be rated as potholes rather than weathering.

The severity of potholes less than 30 inches in diameter are rated based on depth and diameter.

depth	diameter		
	4 to 8	8 to 18	18 to 30
1/2 to 1	low	low	medium
1 to 2	low	medium	high
> 2	medium	medium	high

If the diameter of the pothole is greater than 30 inches, the area is computed and divided by five to find the equivalent number of potholes. The severity of these potholes is medium or severe depending on whether the depth is greater or less than one inch.

The extent of potholes is measured by counting the number that are in each of the severity categories.

<u>Railroad Crossings</u> - In the PAVER system, all railroad crossings that affect ride quality are rated as distresses. The severity is based on the effect on the ride quality and the extent is measured in square feet.

Rutting - Ruts are longitudinal depressions in the pavement surface. They are the result of permanent deformation of the pavement layers, either through consolidation or lateral movement of the material due to traffic loading. Significant rutting can lead to major structural failure.

The severity of rutting is established by the mean rut depth. Low severity rutting is 1/4 to 1/2 inch. Medium rutting is 1/2 to 1 inch and high severity rutting is more than 1 inch. Rut depth is measured by laying a straight edge across the rut and measuring the depth. The mean is computed from measurements taken along the length of the rut.

The extent of rutting is measured in square feet.

Shoving - Shoving is permanent longitudinal displacement of a localized area caused by traffic loading. The traffic loads cause short, abrupt waves in the pavement surface. Normally, this distress only occurs in an unstable liquid asphalt mix pavement.

The severity of shoving is rated based on the influence on ride quality. Low severity shoving causes some vibrations in the vehicle, but creates little discomfort. Medium shoving causes the vehicle to bounce significantly, creating some discomfort. High severity shoving requires a reduction in speed for safety and comfort, and there is a potential for vehicle damage.

Shoves are measured in square feet of pavement area.

Slippage Cracking - Slippage cracks are caused by braking or turning wheels causing the pavement to slide or deform. Usually, the surface is a low-strength mix or there is poor bond between the surface and the next layer. The cracks are usually crescent shaped.

The severity of slippage cracks are rated by the width of the crack and the condition of the pavement in the immediate area. Low severity cracks are less than 3/8 inches wide. Medium severity is defined as either the cracks are 3/8 to 1.5 inches wide or the area around the crack is broken into tight fitting pieces. High severity cracks are wider than 1.5 inches or the area around the crack is broken into easily removable pieces. The entire slippage cracking area is rated according to the highest severity level. The extent of slippage cracking is measured in square feet.

Swell - Swells are long gradual waves more than ten feet long. They are caused by frost action or swelling soils. Swells may be accompanied by cracking.

The severity of swelling is rated based on ride quality. The scales have been previously defined. The extent of the swell is measured in square feet.

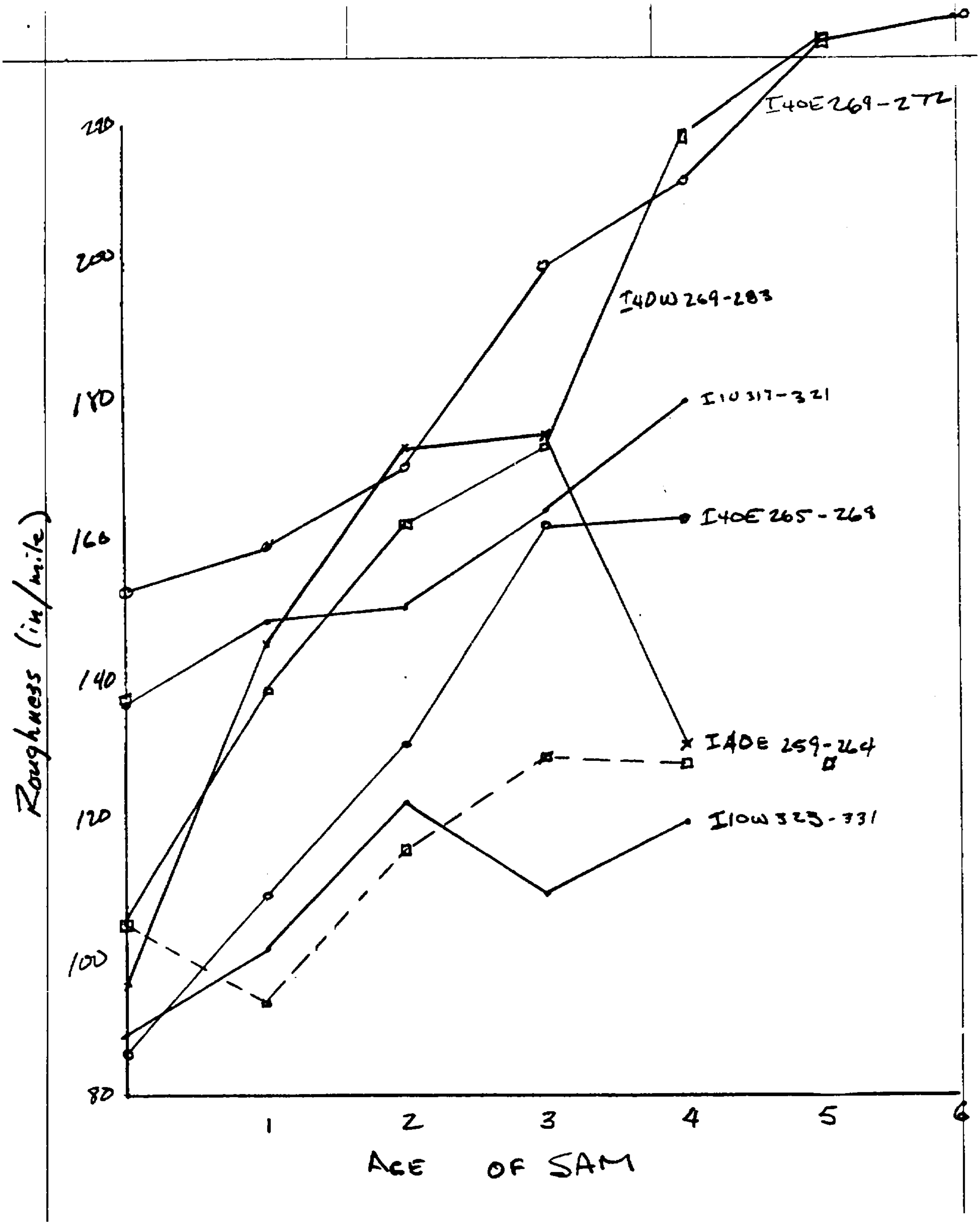
Weathering and Raveling - Weathering and raveling occur when the asphalt binder has hardened appreciably or the surface is a poor quality mix that allows the aggregates to dislodge from the surface. Oil spills can soften the surface leading to raveling.

The severity is rated based on the condition of the surface. Low severity raveling and weathering has areas where the surface has started to wear away and, in some cases, started to pit. Moderate severity has more of the aggregate and/or binder worn away and the surface texture is moderately rough and pitted. High severity weathering and raveling has a considerable amount of the surface worn away and the texture of the surface is very rough and severly pitted. Pitted areas are more than

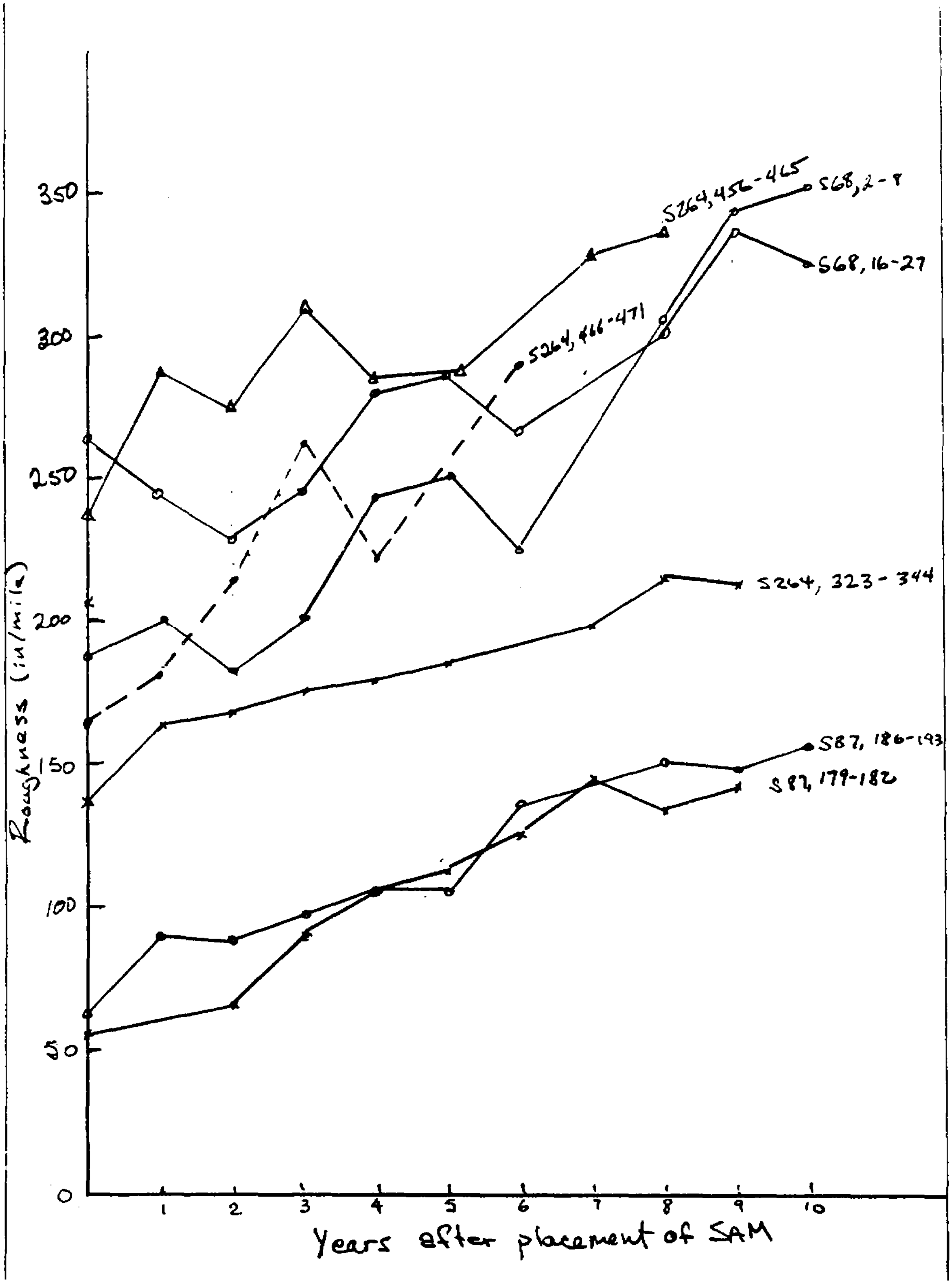
1/2 inch deep or more than 4 inches in diameter, and are counted as potholes.

APPENDIX B

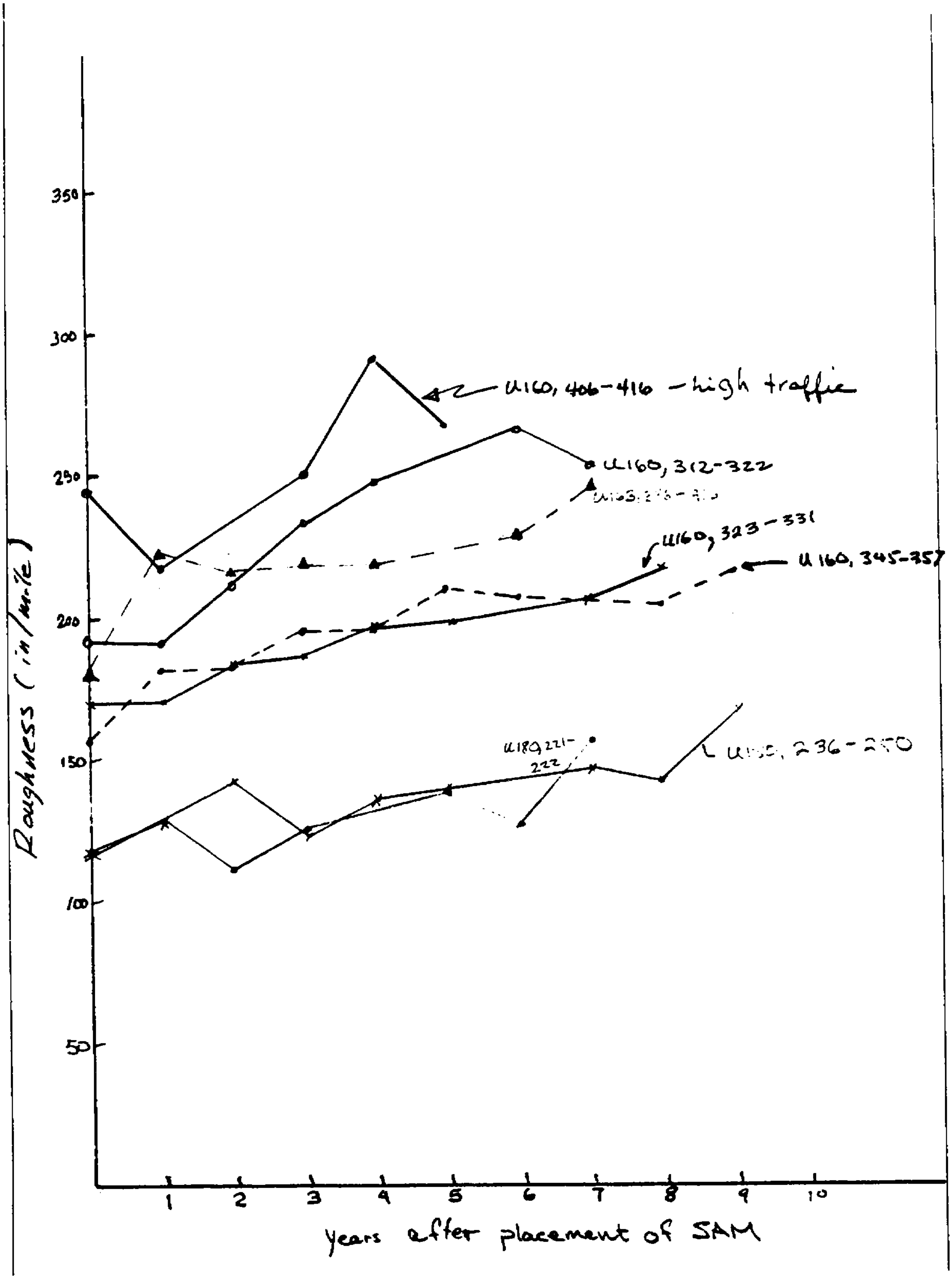
PLOTS OF ROUGHNESS VERSUS TIME



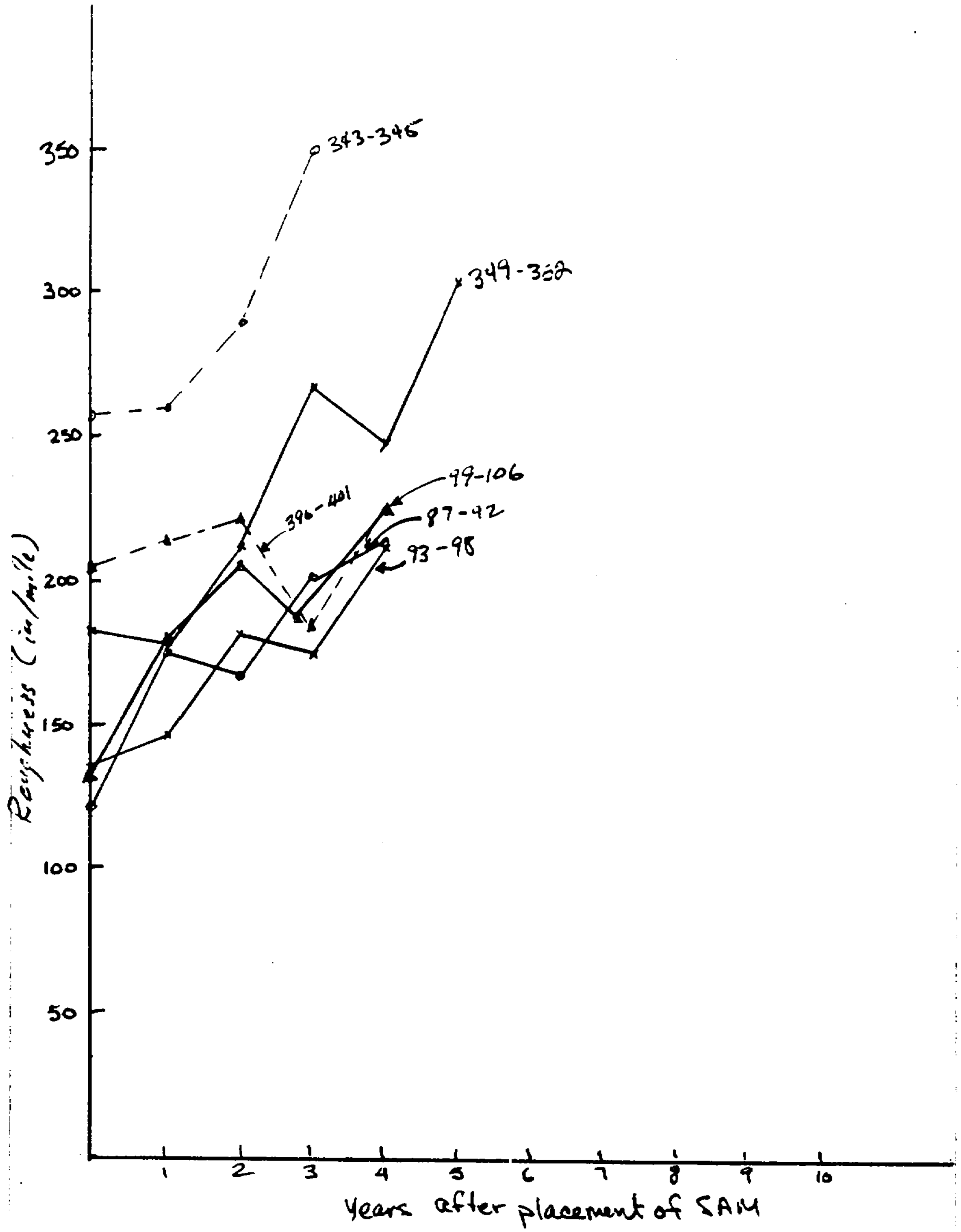
PERFORMANCE OF SAM TREATMENTS ON INTERSTATES



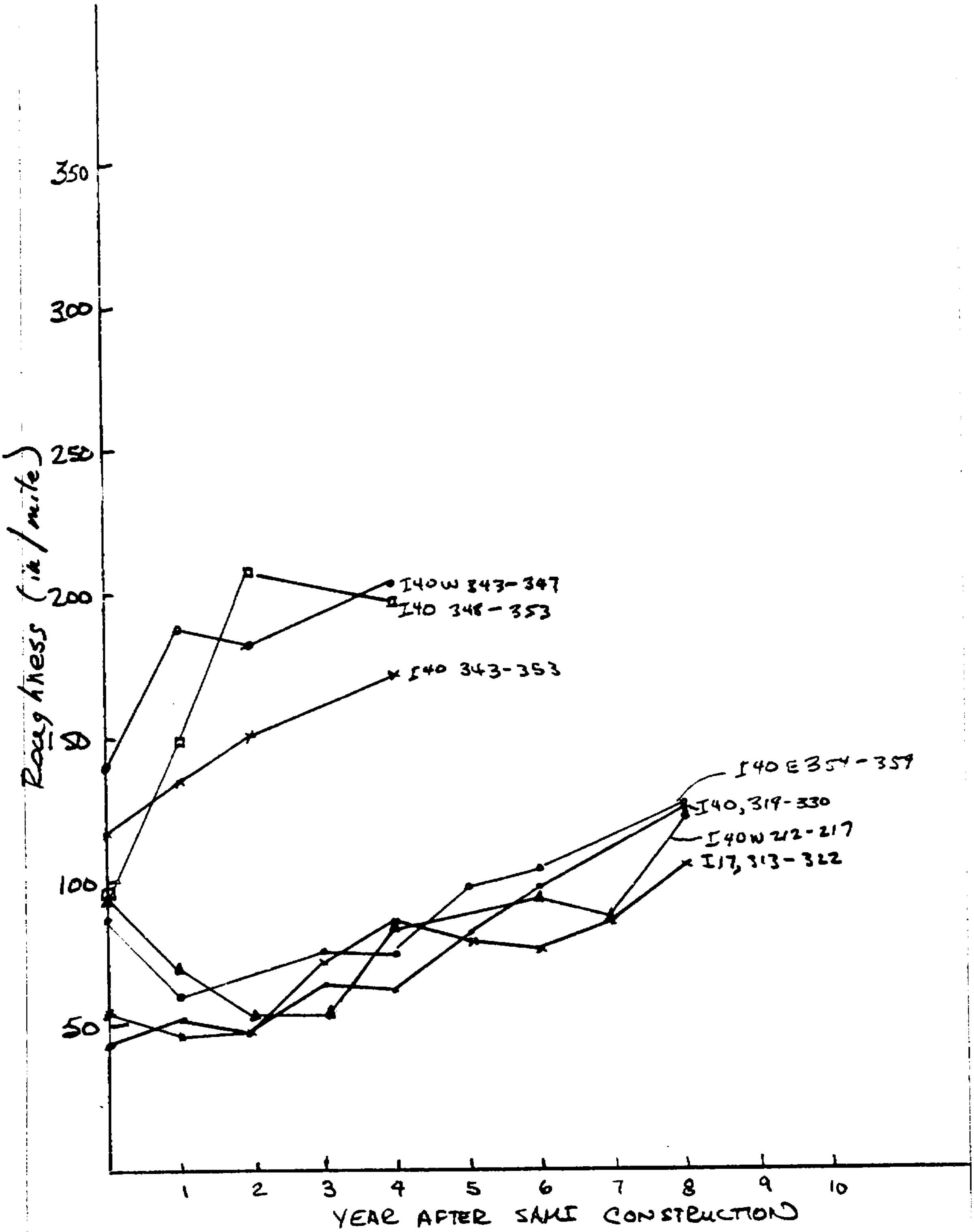
PERFORMANCE OF SAM TREATMENT ON STATE ROUTES



PERFORMANCE OF SAM TREATMENTS ON U ROUTES



PERFORMANCE OF SAM ON ROUTE U60 HIGH TRAFFIC



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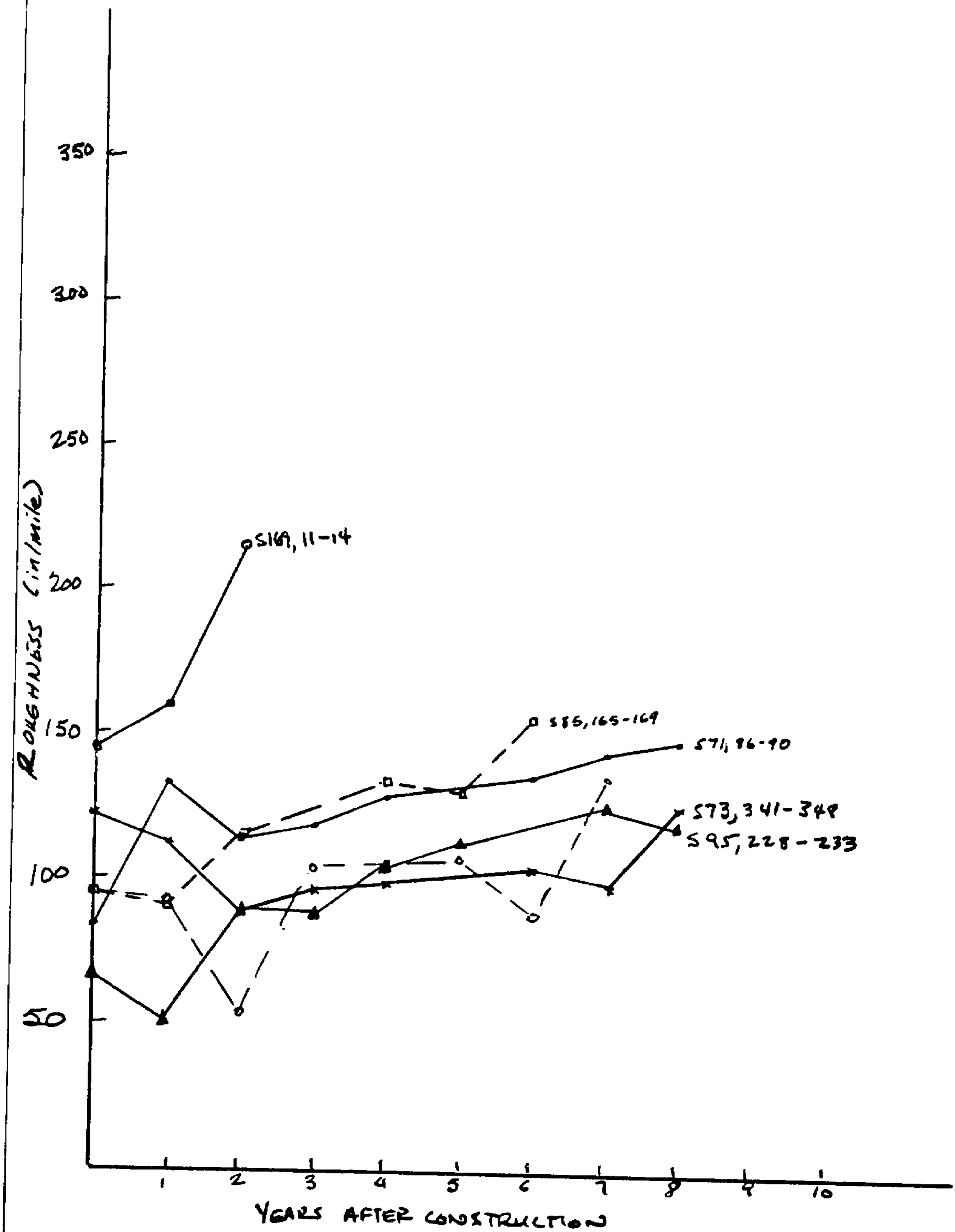

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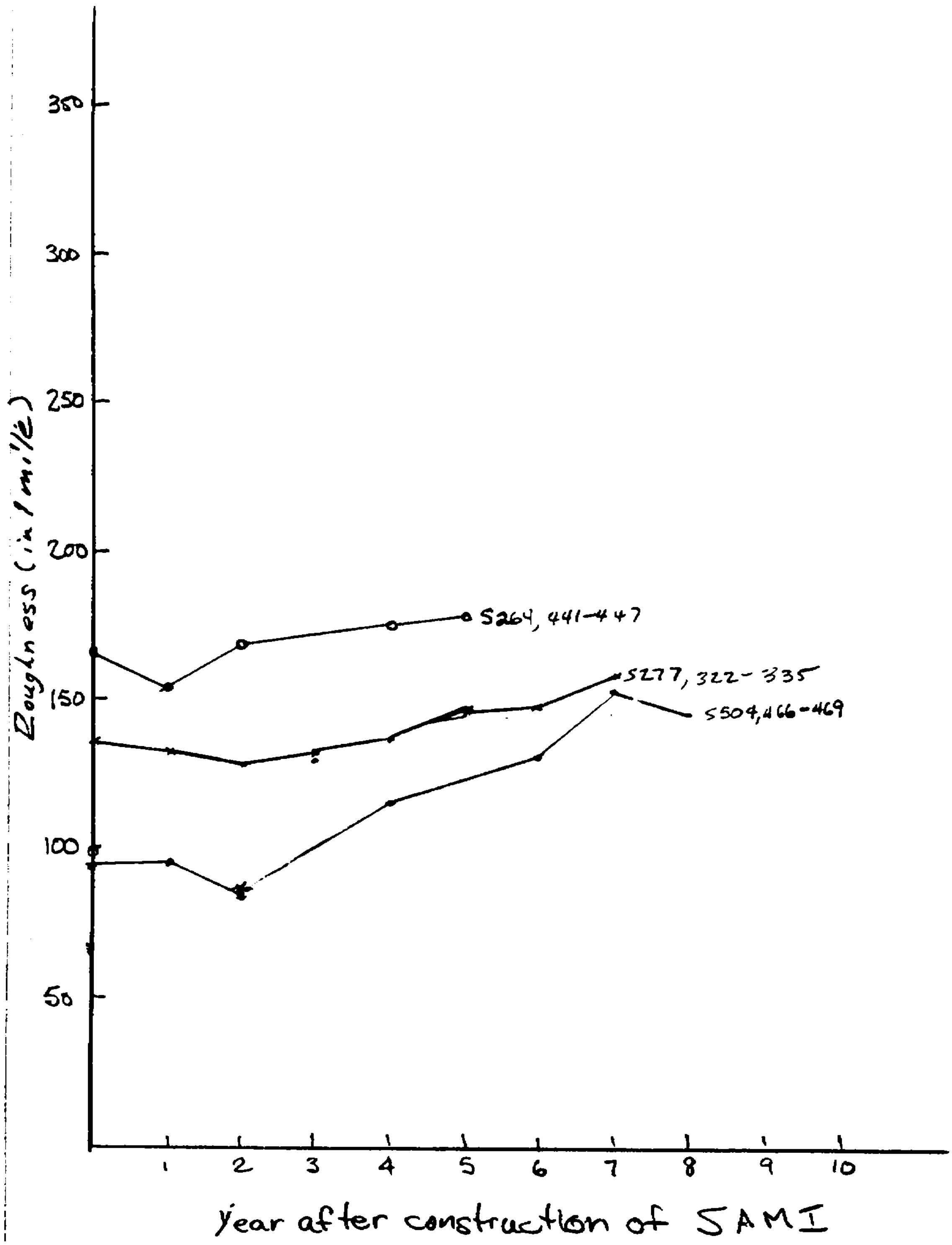
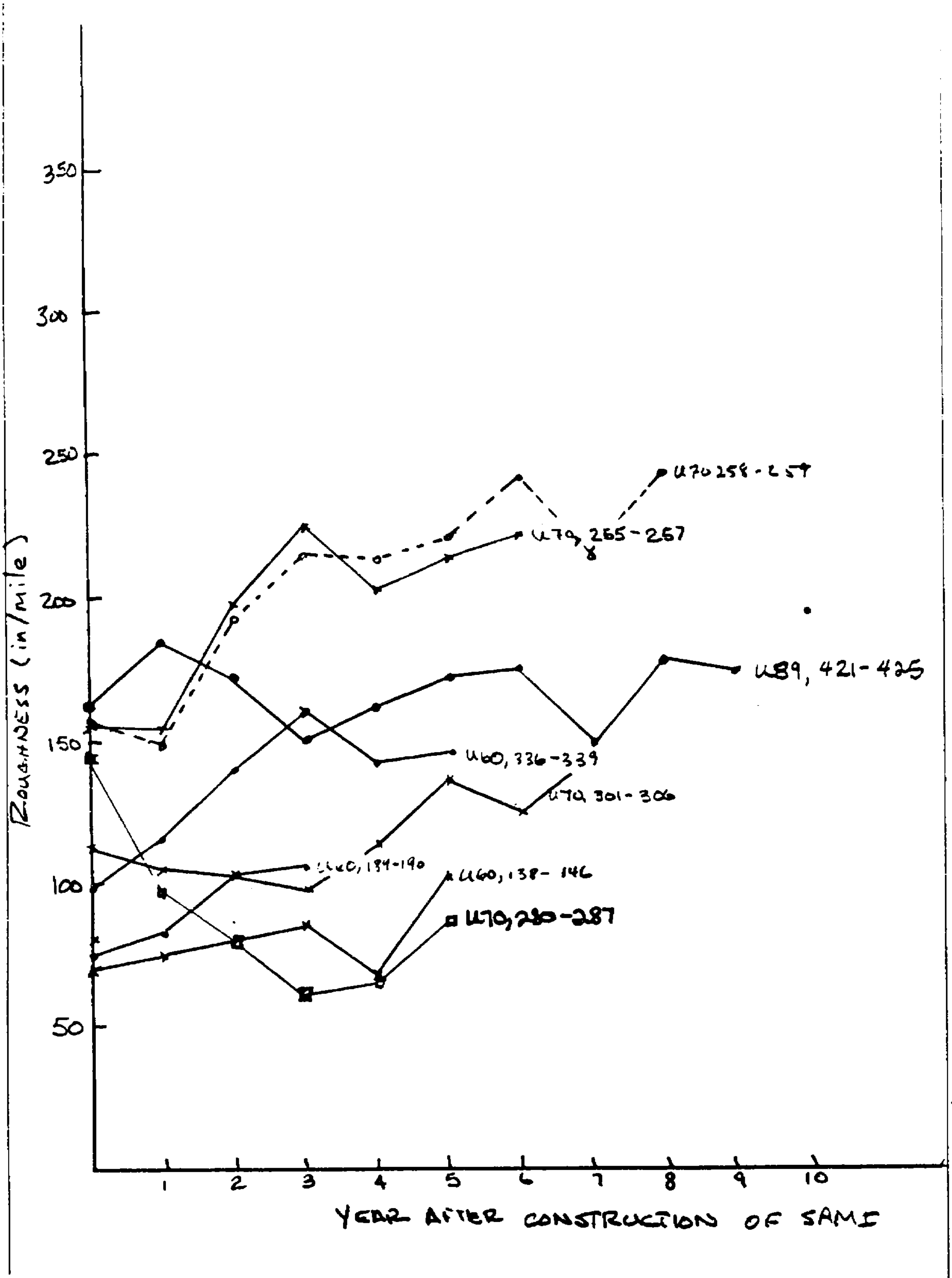


PERFORMANCE OF SAMI SECTIONS ON STATE ROUTES



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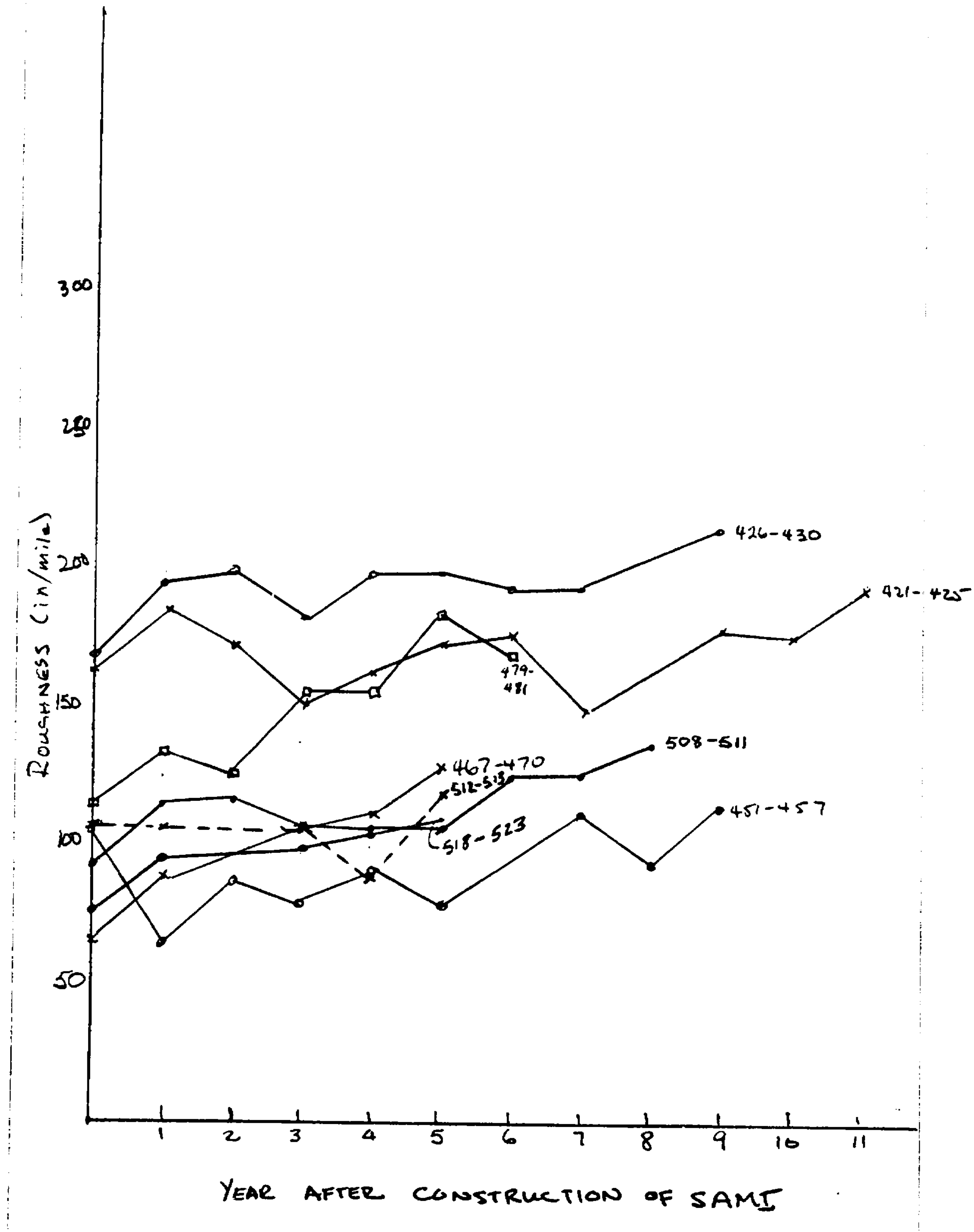

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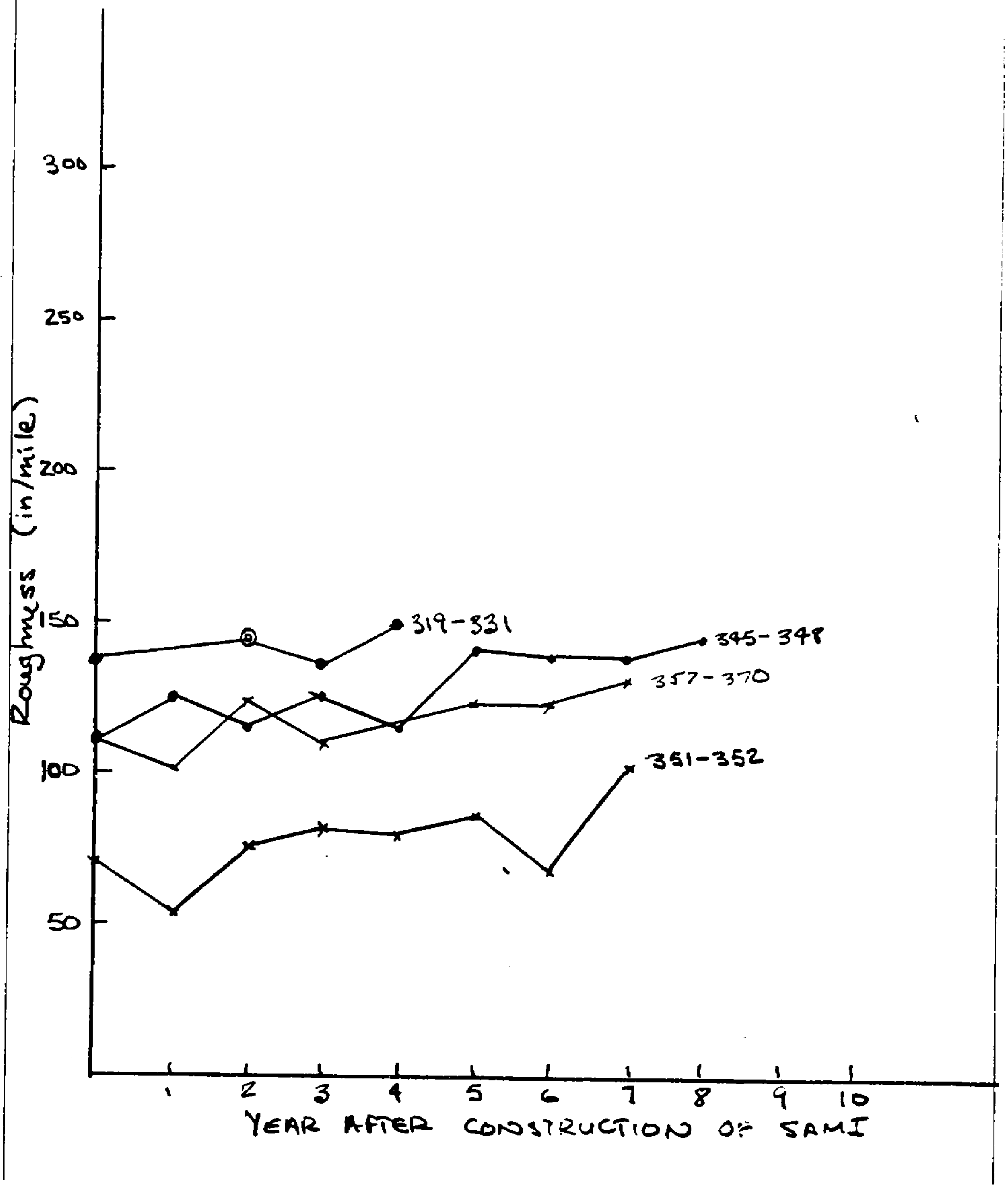

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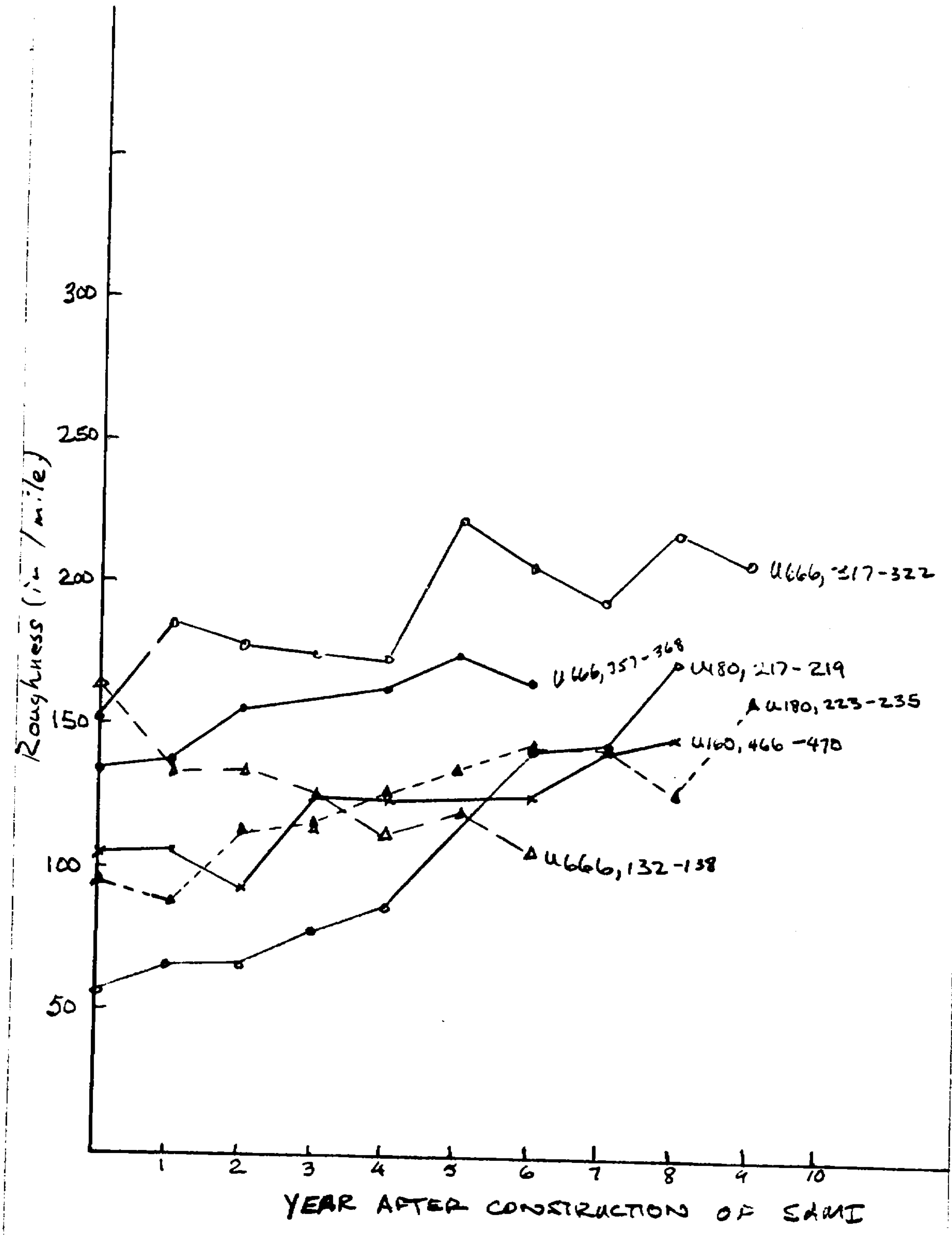

PERFORMANCE OF SAMI SECTIONS